A Farmer's Toolbox for Integrated Pest Management

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RoboWeedMaps in Denmark

Abstract

RoboWeedMaps is a weed management product chain that covers the entire process from weed identification to application of herbicides or mechanical treatments. The product chain includes components developed over the last 30 years of research in integrated pest management (IPM) in Denmark and was developed to a full product chain in the RoboWeedMaps project funded by Innovation Fund Denmark from 2017-2020. The project has demonstrated an average saving in costs of 33 € per ha, equal to 57-73 % for different crops. Significant improvements were also demonstrated for environmental indicators with 24 – 52 % improvements for Treatment Frequency Index (TFI) and 6 – 95 % improvements for Environmental Load Index (ELI). The potential of site-specific treatment compared to field-specific treatment was also tested, but only for one weed species. The results here showed a further reduction of 88 % in herbicide use. Even though the product chain has been demonstrated successfully, further improvements are needed. Most notably, the hierarchical botanical model should be improved from identifying monocots and dicots to deliver information about the family, genus and ultimately species of the weeds The case study on RoboWeedMaps is relevant for this project as a state-of-the-art set of tools supporting farmers in applying IPM. The decision support system part of the chain has shown promising possibilities for application in other parts of Europe.

1. Introduction

In Denmark, there has been research in decision support systems (DSS) for integrated pest management (IPM) during the last 30 years. Among other applications, this has contributed to developing the DSS IPMwise, widely used by farmers and farm advisors to support weed management. IPMwise can be applied to 30 different crops, targeting more than 100 weed species and including 180 herbicides and mechanical treatment.

The commercial RoboWeedMaps product chain was developed within an innovation project funded by the Innovation Fund Denmark in 2017-2020. The product chain integrates different technologies including capturing on-field pictures of weed, automatic picture recognition of weeds, and a decision support system for applying IPM principles in weed management (IPMwise) and lastly, field and site-specific application.

Main questions addressed in the project were:

- What is the economy for the farmers?
- What pesticide amounts expressed as Treatments Frequency Index and Danish Environmental Load Index should be used?
- What is the scenario upscaling to the Danish winter grain area?

Initially, it was estimated that the project could lead to cost savings in weed management of 40% for standard farming practices, and up to more than 80% when using the new generation of injection sprayers in site-specific application.

In the project, the potential of the RoboWeedMaps product chain was compared at field level to planed/already-executed treatments for 84 cereal and maize fields. The results were an average saving of 33 € per ha, equal to 57-73 % for different crops – lowest for winter rye, highest for winter barley. Significant improvements were also recorded for environmental indicators with 24 – 52 % for Treatment Frequency Index (TFI) and 6 – 95 % for Environmental Load Index (ELI). The potential of site-specific treatment compared to field-specific treatment was also tested, but only for on weed species. The results here showed a further reduction of 88 % in herbicide use.

The case study on RoboWeedMaps is relevant for the pilot project as a state-of-the-art set of tools supporting farmers in applying IPM. The product chain covers the entire process from weed registration and identification to application of herbicides or mechanical treatments. The DSS part of the chain has shown promising possibilities for application in other parts of Europe.

2. Research theme

The case study will present an innovative product chain helping farmers to implement IPM principles in weed management from detection of weeds to application of herbicides or mechanical treatment. It will report on the economic costs and environmental impact and benefits of the RoboWeedMaps technology observed through the project implementation. It will also identify barriers to the implementation of the RoboWeedMaps technology in Denmark

based on literature and interviews with stakeholders and farmers. Finally, it will explore the options to replicate the use of/promote the use of the RoboWeedMaps technology in other geographic regions of the European Union.

3. Methodology

The methodology of the case study falls in two parts:

- Firstly, desk research was conducted based on written materials available from public sources. This includes scientific papers, project reports and articles in the farming press as well as resources available on the internet. The main source is the project report from the RoboWeedMaps project 2007-2020 (Petersen et al., 2021).
- Secondly, five (5) interviews were conducted, of which one with a farmer, to explore their experiences with RoboWeedMaps or selected components of the product chain. The focus of the interviews was to gain more knowledge on the product chain and answer questions arising from the desk research, to identify potential barriers for increasing the use of the product chain in Denmark and to explore options for applying the technology in other regions of Europe. All interviews were conducted via telephone.

4. Activities and results

4. 1 Objectives

The overall objective of the RoboWeedMaps project was a significant reduction in herbicide usage, initially in Denmark, but later also worldwide. More specifically, the objective was that the project could lead to savings in weed management of 40% for standard farming practices, and up to more than 80% when using the new generation of injection sprayers allowing site-specific application.

To achieve this objective the project developed a full product chain for weed management from capturing in field pictures of weed, automatic picture recognition of weeds, and a decision support system for applying IPM principles in weed management (IPMwise) and finally, field and site-specific application.

4.2 Governance and functioning of the initiative

RoboWeedMaps and its different components have been developed in a consortium with the following partners:

IPM Consult: https://www.ipmconsult.dk

Conpleks, https://conpleks.com

I-GIS, https://i-gis.dk/en-us/

Datalogisk, https://datalogisk.dk

AgroIntelli, https://www.agrointelli.com

Danfoil, https://www.danfoil.dk/uk/

Department of Electrical and Computer Engineering, Aarhus University, https://vision.eng.au.dk

Department of Environmental Science, Aarhus University, https://envs.au.dk/en/

The RoboWeedMaps project was funded by Innovation Fund Denmark in the period 2017-2020. The Innovation fund reached 2.6 million € of a total budget of 4.6 million €.

It should be noted that some of the components and the knowledge behind stems from other projects conducted over the last thirty years, including projects funded by the European Union such as ENDURE, PURE and IPM Decisions. Parts of the product chain are already commercially available. This includes the decision support tool IPMwise marketed by IPMconsult and Datalogisk and available as a stand-alone online tool and a module in a broader field management programme (https://datalogisk.dk/ipmwise/). Both weed maps and treatment maps can also be purchased from Datalogisk.

4.3 Results (and successes)

The RoboWeedMaps product chain

The main outcome of RoboWeedMaps is development and application of a complete product chain from registration of weeds to application of herbicides in the field. The product chain consists of the following components:

- ***High-speed cameras*** were designed and constructed to take sufficiently good pictures to enable people with some agro-botanical experience to determine weeds in the picture. A dual camera system is embarqued on an All-terrain vehicle (ATV), which can drive by 40 – 60 km/hour when taking pictures in the field. The image density is 5 or 10 meters corresponding to 400 or 100 pictures per ha. The system has a capacity of registration of 30 – 40 ha per hour.

- ***An online tool*** that can: 1) receive and keep track of large amounts of images, 2) automatically perform ML-scrap thumbnail images of weeds, 3) automatically perform machine learning recognition of soil, rocks, crop plants and weeds. The weeds are currently classified as being either monocot or dicot, 4) offer 'virtual field inspections, whereby weeds can be determined manually at family, genus and species level.

- ***A decision support system (DSS)*** for targeted and precise weed control. The RoboWeedMaps product chain integrates the decision support tool IPMwise developed to adapt weed management based on the IPM principles. In the current version (4th generation) the tool can be applied to 30 crops against more than 100 different weed species and includes 180 herbicides as well as mechanical control options. IPMwise is available as a stand-alone online tool or included in a larger software programme on field management (Næsgård Mark). IPMwise ensures that

legal requirements are fully met, and further development of herbicide resistance can also be prevented. Mechanical treatments are advised in selected crops where herbicide treatment is difficult or very expensive. The current number of users of IPMwise amongst farmers and farm advisors in Denmark is not public information due to business considerations. In short, IPMwise provides an overview of possible herbicide- and mechanical treatments in different crop growth stages in a selected crop throughout a full growing season, based on inputs such as crop, season, crop growth stage, water stress, weed name and size, temperature, relative dose, expected yield etc. It is also included in the output if IPM efficacy targets are met and if there is a need for control according to IPM requirements.

- ***Field- and site-level treatment maps*.** In the RoboWeedMaps project, both field- and site-specific treatment plans have been produced. Field-specific treatment plans have been designed based on the weed distribution map and using the value of the 75% percentile in the 5-meter grid to find the treatment using IPMwise. For the site-specific treatment plans, maps were generated using different thresholds for weeds (>= 1, >=2, >=5 and >= 10 plants per sq. m.) leaving room for the farmers and advisors to choose the level. Site-specific treatment maps are provided digitally and compatible with sprayer terminals.

- ***Spraying equipment*.** Within the project, advances have also been made in spraying equipment capable of changing the herbicide mixture and dosage on the fly based on digital maps of the weed population at the specific spot in the field. The system handles up to five different means, each controlled by its own field map, enabling tailoring the spraying to the individual spot and the specific need.

RoboWeedMaps results

In the RoboWeedMaps project from 2017 to 2020, herbicide use and costs were estimated for 84 fields where the crops were cereals and maize, RWM treatments were compared with the farmer's planned/completed treatments. By optimising treatments using the RoboWeedMaps approach at field level, herbicides savings were achieved corresponding to 33 € per ha (57-72% in different cereal crops), to 0.87 Treatment Frequency Index (TFI) (24 – 52 %) and to 0.86 Environmental Load Index (ELI) (6 – 95 %).

To this it can be added additional potential in the transition to site-specific treatment. The potential of site-specific treatment compared to field-specific treatment was also tested, but only on weed species. The results here showed a further reduction of 88 % in herbicide use. However, exact quantification of this can only be done when RoboWeedMaps can automatically also determine weeds at the family, genus or species level. RoboWeedMaps is currently tested in large-scale field validation trials, where the efficacy on weeds of the RWM is compared to efficacy of best practice treatments. Results are expected during 2022.

As mentioned above the initial objective was to reduce the use of herbicides by 40% for standard farming practices, and up to more than 80% when using the new generation of injection sprayers allowing site-specific application. The results of testing the RoboWeedMaps approach in the project are differentiated on different crops and different indicators (cost,

Treatment Frequency Index and Environmental Load index) making it difficult to compare directly with the more general overall objective stated at the beginning of the project. However, it is clear that the approach has demonstrated substantial reductions in the use of herbicides. This has mainly been demonstrated at field-level, whereas further results are needed for site-specific application.

The RoboWeedMaps project have been communicated widely in the Danish farming community at conferences, webinars and in the agricultural press. To some degree, the project has also been disseminated at international conferences. (See sources).

Application beyond Denmark

The DSS component of the RoboWeedMaps product chain, IPMwise, has already been applied/tested to various extent in Norway, Estonia, Poland, Germany, Italy, Spain and Slovenia. Work in Greece is in progress. So far, IPMwise is available in the languages Danish, English and Spanish. It is assessed that IPMwise as it is applied in Denmark also can be applied in the Southern part of Sweden and northern parts of Germany, with precaution to national registrations of herbicide product

For Spain, the use of IPMwise has been validated for weed control in winter wheat and maize (see: https://ipmwrces.azurewebsites.net/default/es-es/). To enable the application in Spain, two issues had to be solved: Generation of dose–response curves for Spanish-relevant weed species and calculation and adjustment of the shift of the dose–response curves according to phrenological stages of the weed species (Montull et al. 2020). Montull at al., 2020 further concluded that IPMwise have the potential to decrease amounts of applied herbicides by at least 30% in Spanish cereal agricultural systems.

4.4 Barriers (to implementing the project)

Barriers for the uptake of the technology by farmers in Denmark

The barriers for farmers to use the RoboWeedMaps technology has been analysed based on outputs from focus groups and in individual interviews with farmers in the report: Landmænds oplevelse af barrierer og muligheder for præcisionsteknologi til ukrudtsbekæmpelse – baseret på interviews om konkret RoboWeedMaps-teknologi (Pedersen and Nielsen, 2021).

In general, farmers are very positive towards the technology and mentions time savings, economy and functionality as determinants for investing in RoboWeedMaps.

The report points to the following barriers:

- Lack of user-friendliness, robust in use and compatibility with other system elements and machinery;
- Lack of flexibility in terms of the possibility for the farmer to influence decisions (degree of automation);

- Lack of thrust in stated reductions in herbicide use;
- Lack of possibility to buy single parts of the system and not necessarily the whole package;
- Lack of availability of the system on subscription; and
- Some farms are too small or has a cropping pattern that makes the technology unattractive.

Identified technical barriers

Currently, the automatic weed recognition only determines weeds as monocot and dicot. The hierarchical botanical model needs to be improved to deliver information about the family, genus and ultimately species level to identify and optimise options for application of herbicides. Currently, this is remedied by a 'Virtual field inspection' where the photos used for the automatic recognition, is assessed by farmers/farm advisors to identify the weed. The decision support system component (IPMwise) already works at species level. Some farmers would like to have registration, identification and treatment in the same process, but currently it is only realistic to implement the process over two days.

In Denmark, approximately half of the farmers have equipment for spot-spraying allowing optimal implementation of the RoboWeedMaps product chain. However, not all of these are able to spray with the same precision as RoboWeedMaps offer. With 400 pictures per ha the RoboWeedMaps requires capacities to handle big data. A field of 10 ha requires 20-terabyte storage capacity.

Barriers for implementing RoboWeedMaps in other geographical areas

The consortium behind RoboWeedMaps have provided detailed potentials and requirements for scaling up RoboWeedMaps to other geographic regions of Europe. It is estimated that introduction of IPMwise and RoboWeedMaps in other countries will require at least a 3-year project with national partners. Main points are to (1) establish required dose-response curves, (2) integrate national agronomic and legal conditions in the decision support component, (3) provide images of relevant weeds for machine learning, (4) Test adapted RoboWeedMaps version in field trials for at least 2 years and (5) analyse opportunities and barriers for using RoboWeedMaps in the new context.

5. Discussion and conclusions

There is an important potential for reducing the environmental impact of weed management by minimising and optimising weed treatments according to needs at field or below field level. The RoboWeedMaps product chain is a big step forward towards an automated process for supporting the farmers in achieving this.

The product chain integrates different technologies from capturing in field picture of weed, automatic picture recognition of weeds, a decision support system for applying IPM principles in weed management (IPMwise) and finally, field and site-specific application.

The RoboWeedMaps approach has the largest potential in spring cereals because relies on that, the weed is sufficiently established to be recognised. This is a problem in winter cereals, maize and beets, where the weed treatment is required at a very early stage. It is also assessed that with the current state of the technology, the use is most promising in weed management in fields with low weed pressure or weed management targeting specific weeds.

The RoboWeedMaps project has demonstrated an average saving in costs of 33 € per ha, equal to 57-73 % for different crops. Significant improvements were also demonstrated for environmental indicators with 24 – 52 % improvements for Treatment Frequency Index and 6 – 95 % improvements for Environmental Load Index. The potential of site-specific treatment compared to field-specific treatment was also tested, but only for on weed species. The results here showed a further reduction of 88 % in herbicide use.

However, the development of the technology is still in progress. Currently, the economic benefits for the farmers are not sufficient to drive the technological advances, which means that public support is required. This could be in the form of specific support for projects, but also a more general prioritisation of precision farming or higher taxes on herbicides.

A future big step forwards for the approach would be to improve the hierarchical botanical model from identifying monocots and dicots to deliver information about the family, genus and ultimately species of the weeds.

Even though the full product chain has been demonstrated successfully, a further development of the technology to allow more precise application in the entire process from registration to treatment is also needed.

Parts of the RoboWeedMaps product chain has already been launched in other European countries and therefore covers a large geographic area. In addition, the entire product chain has potential for replicability and scale-up by implementation in additional EU Member States. However, it is also pointed out by the Consortium behind the approach, that robust implementation requires up to three years of preparatory work.

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Web-resources

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https://www.youtube.com/watch?v=0kyVdqTPuFE
https://www.youtube.com/watch?v=gUlMh-I-mUE&t=2s
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Interviews

Interviews were conducted with:

Per Rydahl, IPMwise
Poul Henning Petersen, SEGES
Birger Hartmann, Datalogisk
Kristian Boel Østergård, farmer
Andreas Skov Rasmussen, Agrovi