EIP-AGRI Focus Group

Non-chemical weed management in arable cropping systems

STARTING PAPER - REPORT

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Motivation on the Focus Group Non Chemical Weed Management

Weeds compete with crops for water, nutrients and sunlight. Some weeds can also be a host for pests and diseases that can be transmitted to the crops. As weeds therefore threaten crop yield and quality, farmers fight against them and the most common weed management practice is the use of herbicides. Effective weed management is an important fundament of modern agriculture. Agriculture in the EU and worldwide has become increasingly dependent on the use of herbicides and of pesticides in general, which has helped boost agricultural yield and food production. As a result, herbicides have become the foundation of weed management in today's arable cropping systems. Off all pesticides sold in the European Union 33% were herbicides, haulm destructors and moss killers (Eurostat Source: European Union, European Parliament. (2015), Draft Report on Technological solutions to sustainable agriculture in the EU (2015/2225(INI)). At the same time, pesticides can have effects on the environment, non-target organisms and animal and human health. Therefore, EU and Member State policies seek to reduce reliance on pesticides by designing and implementing more integrated approaches for pest management, while at the same time safeguarding the competitiveness of agriculture in the EU.

Developing and/or promoting non-chemical weed management techniques could contribute to reducing the risks linked to the use of herbicides. These management techniques range from preventive to curative strategies (e.g. crop rotation, cropping systems, tillage, mechanical weed control, use of alternatives to critical active substances) and cover both the organic and the conventional sectors.

Tasks of the Focus Group Non Chemical Weed Management

The Focus Group is expected to carry out the following main tasks:

- Make an inventory and clustering of non-chemical weed management practices in arable cropping systems for the different pedo-climatic zones in the EU;
- Analyse challenges and opportunities regarding the implementation of these practices, notably in terms of reliability and cost effectiveness at farm level as well as their transferability to other conditions (location, type of production);
- Identify key factors (such as knowledge requirements, decision support tools, partnerships) and analyse technical/economic/social barriers related to the adoption of these practices by farmers;
- Analyse the interaction of non-chemical weed management practices with other challenges, such as carbon sequestration, nutrient losses, soil degradation/erosion/compaction and biodiversity;

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- Collect good practices and success stories on reducing herbicide use from different European areas, taking into account experiences of farmers and advisers as well as the findings of potential innovation activities carried out by EIP-AGRI Operational Groups and research projects in this field;
- Propose potential innovative actions and ideas for Operational Groups to stimulate the use and improvement of non-chemical weed management;
- Identify needs from practice and possible gaps in knowledge concerning non-chemical weed management which may be solved by further research.

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Bottlenecks to overcome and areas for development for non-chemical weed management in arable systems

Weed control in current arable plant production systems is for a large part depending on herbicide control. Alternatives are available, but the lack of adoption of these strategies, tools and technologies at a large scale, has multiple causes which are of both technologically as well as socio-economic nature (Neve, 2017, Liebman 2016). These form the bottlenecks towards non chemical weed management in arable systems at a large scale that need to be overcome in arable cropping systems today, but also in future. Major areas for development can be distinguished for non- chemical weed management systems in 2050, but it is important to realise that these areas have different timelines and different rates of development. In this chapter we describe the available alternatives and bottlenecks today and major areas for development in future (2050).

Alternatives and bottlenecks today, Use of multiple tactics: Integrated Weed Management (IWM)

Currently, herbicides are easy to use and highly cost effective compared to existing alternatives. Alternative methods need to be combined in a IWM (integrated weed management) strategy to reach acceptable levels of weed control. The elaborated description of the IWM approach and ***current*** alternatives is described in the following paragraph.

Factors affecting farmers perception of weeds and weed management and their adoption of alternative weed management can be biophysical, economic, technological, individual, or socio-economic (Figure 1, the IWMPRAISE project (**www.iwmpraise.eu**). Although biophysical in nature, environmental factors such as soil compaction and CO_2 sequestration can be seen as a separate category since they reflect trade- offs between herbicides based systems and other environmental goals.

IWM

Herbicides are easy to use and cost effective compared to existing alternatives.

Alternatives need to be combined to be just effective. This combined use of alternatives is called Integrated Weed Management (IWM).

IWM uses tools and techniques that enable:

a) the use of diversified cropping systems,
b) use of weed suppressive and competitive cultivars,
c) adequate field and soil management,
d) targeted control, and
e) monitoring and evaluation.

Barriers preventing the adoption of IWM by farmers can be biophysical, economical, technological, individual or socio-economical.

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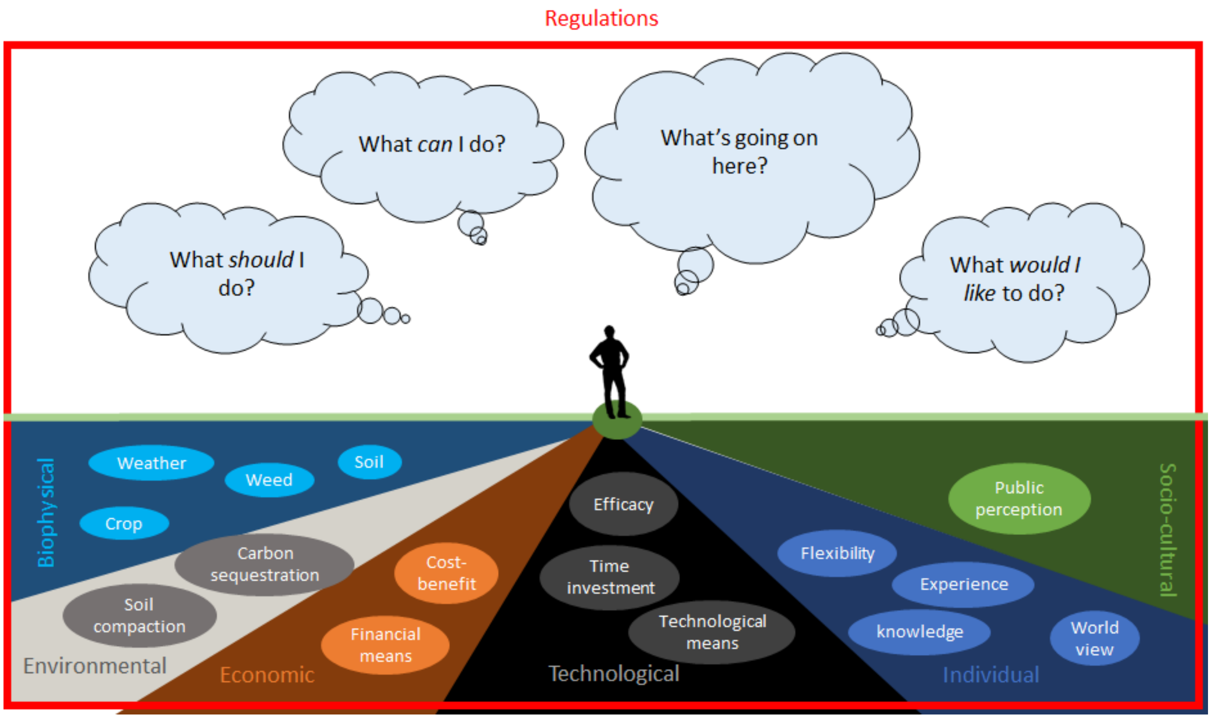

Figure 1. Depiction of the factors affecting farmers perception of weed management. Adapted from www.iwmpraise.eu.

Herbicides are a single tactic solution that are easy to use for a farmer. On top of that, they are usually highly efficient. Non chemical weed management is more complex and knowledge intensive. It requires the use of a combination of several tactics into an integrated weed management (IWM) strategy (Riemens and Moonen, 2018). In IWM strategies non chemical weed control tactics target weed populations during several parts of the weed life cycle (Bastiaans et al., 2008). The choice for farmers is which tactics to combine in order to efficiently manage weeds. Successful integrated non chemical weed management strategies will combine multiple tactics (Chikowo et al 2009, Liebman and Gallandt, 1997) from all of most of the following classes (Figure 2, **Riemens and Moonen, 2018**):

a) the use of diversified cropping systems,
b) use of weed suppressive and competitive cultivars,
c) adequate field and soil management,
d) targeted control, and
e) monitoring and evaluation.

Figure 2. The five classes for Integrated Weed Management (Riemens and Moonen, 2018).

The five classes and their role in Integrated Non Chemical Weed Management are described in the following paragraphs.

The use of diversified cropping systems

A large number of weeds is able to grow and survive in arable fields. Each crop will unintentionally select for specific weed species that resemble the crop best, that are most able to compete with the crop, and that can avoid or survive crop-specific soil- and weed management. The weed community in an arable field will, therefore, tend to consist of a few dominant, crop-specialized and highly competitive species and a large number of crop-generalists that can survive in arable fields but that pose no or only a minimal threat to crop yield or quality. Because highly competitive, dominant weeds form a large proportion of the weed flora, suppressing this part of the weed flora results in a significant reduction of the problem. Crop rotation is therefore one of the pillars of sustainable weed management strategies in arable cropping systems because it diversifies timing of sowing, soil cultivation, fertilization and possibilities for mechanical control. It comes in two forms; diversification over time (crop rotations) and over space (intercropping).

DIVERSIFIED SYSTEMS

A large number of weeds is able to grow and survive in arable fields. Each crop will unintentionally select for specific weed species that resemble the crop best, that are most able to compete with the crop, and that survive crop-specific management.

The use of different crops will change growing conditions for the weeds and will help

Rotating crops means that the growing conditions for weeds change between years or even seasons. Weeds that thrive in one crop are suppressed by the next crop. The more dissimilar the crops in a rotation, with regard to planting and harvest dates, crop phenology and structure, nutritional demands, and timing and type of weed management, the more challenging it will be for crop-specialist weeds to dominate the weed community (Liebman & Staver, 2001). The more crops grown in a rotation, the lower the probability that

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weeds are able to dominate the field. Intercropping systems can either consist of a main cash crop and a non cash crop that prevents weed growth between crop rows, or consist of two main crops with different traits that leave a minimum of nutrients, water and lights for the weeds to grow. Cover crops or green manure crops are non cash crops that are not grown to be harvested, but ploughed into the soil to increase soil organic matter and fixate nitrogen. Cover crops can help deplete the soil weed seed bank when grown for a short period of time. Weed seedlings emerging simultaneously are outcompeted by the cover crop or weeds are terminated before producing seeds, together with the cover crop. Cover crops grown for a longer period, one or two growing seasons, can be used to deplete perennial weeds. They compete for light, nutrients and water with the perennial weeds and can reduce or even deplete the weeds below ground reserves. When these crops can be combined with mowing, their use can be very effective for perennial weed control. Some cover crops contain allelopathic compounds than can inhibit weed growth (Kruidhof et al 2008). Allelochemicals can either be excreted during cover crop growth or released during cover crop termination.

The use of weed suppressive and competitive cultivars

Herbicide resistance has been the major focus of many breeding programs. The introduction of these crops has resulted in an increased global dependence on herbicides in arable systems. A shift towards breeding programs selecting for weed-suppressive genotypes can potentially reduce the need for weed management and control without the environmental benign side effects. Early soil coverage, optimal use of light, water and nutrients for a high competitive ability and the ability to grow in intercropping systems (matching niches) are important elements to be included in these programs that help reduce the need for weed control with herbicides.

An example are short season maize cultivars that allow for a delay in sowing date enabling the use of a stale seedbed prior to sowing the main crop, or allow for early harvest and the growth of a competitive cover crop after wards.

Adjusting sowing patterns and seed rates can be used to allow mechanical weed control in crops in which this option normally does not exist. For instance, an increased row with in cereals of 18-23 cm combined with an increased seed density allows mechanical weeding during crop growth and increases the competitive ability of crops during the early growth stages (Melander, 2003; Kolb, 2012).

CULTIVAR CHOICE

Cultivars vary in their competitive ability for light, nutrients or water. Some cultivars can also suppress certain weed species better than others.
Choosing the right cultivar will help weed management. Future breeding programs that focus on the development of these cultivars are necessary.

The role of adequate field & soil management

Primary tillage is the first major soil working operation carried out to reduce soil strength, to cover plant material and to rearrange soil aggregates. Primary tillage is usually performed at a depth of 15-30 cm,

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depending on the soil type. Primary tillage can bury seeds at a large depth from which seeds are unable to germinate, since most seeds germinate from the top 5 cm of the soil. Secondary tillage operations are much shallower and used to prepare the seed bed and incorporate amendments such as fertilizers. These operations can be used to deplete the soil weed seed bank. Seeds of many species are sensitive to short exposures to light at a certain moment in the life cycle of the seed. One major reason for the enhanced germination of the weed seeds in the soil during the preparation of a seedbed is the exposure to light. The use of a stale or false seedbed uses this sensitivity to promote the germination of weeds, a number of days or weeks before the actual sowing or planting of the crop. This initial seedbed preparation is then followed by destruction of the emerging weed seedlings with minimal soil disturbance to prevent new flushes of weed germination. When mechanical weeding tools are used for the destruction, tillage should be more superficial than the first operation to avoid germination of new flushes of weed seeds (Riemens et al 2007).

FIELD & SOIL MANAGEMENT

Tillage can be used to reduce the number of weed seeds in the soil. Seeds of many weeds will germinate after exposure to light during soil cultivation.
After the initial soil cultivation seeds will germinate. After 2 to 4 weeks a second, somewhat shallower cultivation can be done to kill these weed seedlings.

Targeted Control tools in arable farming systems.

Targeted non chemical weed management tools are needed when the preventive measures to prevent weed seedling establishment in a crop were insufficient to prevent weed damage to the current crop due to competition or insufficient to prevent an increase in the weed density that can cause problems in following crops.

Different types of non chemical weed management tools can be distinguished, based on their scale of operation (full field, interrow, intrarow) and different types of "mode of action" (mechanical weeders, electroweeders, thermal weeders (steam, hot water and flame weeders)).

Full field weeders are applied broad cast on the entire field or crop. Examples are the cultivator, harrow, comb cut, rod weeder and broad cast knife. Important aspects are the timing and the intensity of application which determine the selectivity (Kurstjens, 2007).

A cultivator can be equipped with rigid or more flexible tines of 40-60 cm. The tines can be rigid for more aggressive work, or more flexible for milder operations. The tip of the tines can have wide or narrow teeth with different effects on weed control and soil. Harrows can be equipped with different kind of tools (vertical discs, blades, and flexible or rigid tines). The different tools have a different effect on soil and weeds, and can be combined to increase efficacy. The harrow can be used for control of small seedlings, and is best applied between sowing and crop emergence or in a firmly rooted crop. Harrows can be powered to improve efficacy. An extended description of the tools can be found in Peruzzi and Satori (1997). The comb cut is a tool that does not work the soil. It is a series of knives that cut the weeds but lets the crop (monocotyledons, cereals)

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slide through the teeth. The stems of the weeds must be firmer than that of the crop. The rod weeder and broad cast knife can be used to control perennial weeds, in the intercropping period. These tools are based on a rod or bar that are pulled through the soil that either pull (rod) or cut (blade) the roots of deep rooting weeds.

Interrow weeders operate between the crop rows. Interrow cultivation can be carried out by inter-row cultivators, discs, brush weeders, rotary cultivators, rolling cultivators, basket weeders and rolling harrows. The most important innovation for interrow weeders is the development of guidance systems that take over the role of the driver. They allow for a larger treated area and higher forward driving speeds. Physical guidance systems that follow the crop row are widely available and cheap. The downside is that the crop needs to be firmly rooted and capable of guiding the equipment.

Intrarow weeding is the most challenging cultivation since the risk on crop damage is highest when removing weeds growing close to the crop plants. Available tools are torsionweeders, fingerweeders, flame weeders, and air pressure weeders. During the last two decades two developments have led to major innovations for intrarow weeding: the combined use of cameras and computer vision, and the development of RTK GPS (real time kinetic global positioning) systems. Computer vision technologies are able to recognise the crop row based on shape, colour and location and steer the weeding device in the crop row to cut, uproot, burn or burry the weeds. The last step is the development of the autonomous robotic weeders with non chemical actuation.

Commercial intrarow weeders have been developed. As an example, the Robovator intrarow cultivator from Denmark is equipped with two flat-blade tines per crop row that undercut weeds at 1 to 2 cm below the soil surface. The tines are positioned in the intrarow area until they approach a crop plant, at which point the computer system opens the tines to safely pass by the crop, then closes them again on the following side (Melander et al. 2015). Other examples of commercially available automated intrarow weeders are Robocrop InRow weeders (**www.garford.com**, accessed 12 November 2018) and *Steketee IC* weeder (**www.steketee.com**, accessed 12 November 2018).

TARGETED CONTROL

Targeted non chemical weed management tools are needed when weeds form a threat to the yield of the crop or when weeds will produce seeds that can cause problems in following seasons.

Examples are mechanical weeders, thermal weeders, or electroweeders.

These can either control weeds in the crop row or between crop rows. The development of tools for control in the crop row is the

Monitoring and evaluation

Farmers collect a lot of data from their fields, including weeds and weed management. Data that can be used to evaluate the development of the weed population and the efficacy of control. Several farm management systems facilitate the use of DSS (decision support systems) to control weeds with reduced herbicide rates. The combined use with satellite images, cameras mounted on drones, tractors and weeding equipment or even hand held systems, helps monitor weed patches, individual plants and in future, even species. The next step in the development is to integrate these components into a farm management system that allows the combined storage and analysis of field data and information on weeds and non- chemical weed management. Nowadays, these technologies are available on the market, but the connected use is very limited.

Table Matrix of the five classes for IWM and the barriers for adoption in near future. Dots indicate a significant barrier for adoption of the IWM class.

class	Alternative non chemical weed management	**Biophysical**	**Environmental trade off**	**Economic**	**Technological**	**Individual**	**Socio-cultural**
Diversified cropping systems	Green manure crops						
	Cover crops	•		•	•		
	Intercropping			•	•	•	
	Mixed cropping			•	•	•	
	Crop rotation			•		•	
Use of weed suppressive and tolerant varieties				•	•	•	
Field & Soil Management	Tillage	•	•				
	Sowing densitiy	•					
Targeted Control	Full field	•	•	•		•	
	Intrarow weeders	•	•	•	•	•	
	Interrow weeders	•	•	•		•	
Monitoring & Evaluation	DSS			•	•	•	
	Sensors	•		•	•	•	

Areas for Development in 2050

Previous paragraphs described current developments in non chemical weed management. The following paragraphs describe possible scenarios and areas for development in 2050. Areas for development foreseen in 2050 are diversified systems, breeding for weed competitiveness and suppressiveness, precision agriculture and robotics, bioherbicides and control and data driven socio economic and knowledge exchange.

AREAS FOR DEVELOPMENT IN 2050

Areas for development foreseen in 2050 are:

A) diversified systems: developing competitive mixed cropping and intercropping systems and appropriate mechanization

B) breeding for weed competitiveness and suppressiveness through a focus on the molecular and physiological level

C) precision agriculture and robotics: automated robots that recognise weeds based on hyperspectral imaging and machine learning techniques

D) bioherbicides based on plant extracts or microbes

E) data driven socio economic and knowledge exchange

Diversified systems

The most effective method of diversifying arable cropping systems for weed management is to diversify the crops grown. Widening the crop rotation diversifies factors that impact the weed population dynamics directly, such as: timing of sowing, type and timing of soil cultivation, fertilization and possibilities for targeted direct control. It comes in two forms; diversification over time (crop rotations) and over space (intercropping). Diversification over time is simpler to achieve than the one over space. Possible barriers are the absence of specialised crop management equipment and linked financial investments, knowledge and experience with the crop and the ability to find a market for the crop. At a regional level it will impact the value chain from production to process of the harvested product, of both newly implemented as well as existing crops in the rotation.

Diversification over space requires development of intercropping and mixed cropping systems. In order to achieve this, crop and weed ecological principals as well as development of suitable mechanization need to be developed. Where in the past decades mechanization determined the possibility to implement ecological principles, in future ecological principles will determine the type of mechanization. This paradigm shift is possible to the fast developments in machine learning, vision technology and robotics that enables us to monitor and manage these ecological principles (Visualised in figure 3). Other possible barriers lie in breeding for diversified systems, knowledge of farmers, financial investments and regulations of registration of these systems.

Breeding for weed competitiveness and suppressiveness

Crop breeding for improved ability to compete with weeds has long been a goal for weed science. Focus has been on the identification of morphological traits. However, the search for enhanced weed-competitive crops based on morphological traits has not resulted in the knowledge required by plant breeders to reliably enhance the competitive ability of crops with weeds (Westwood et al 2018). Another approach would be to focus on the mechanism of competition at the molecular or physiological level and the interaction between neighbouring plants. Future seed treatments could be used as triggers for crop plants to withstand physiological stress caused by stress. Crops (genetically) modified or traditionally bred to produce weed-fighting chemicals (allelochemicals) represent another possibility for breeding programs (Westwood et al, 2018).

Precision agriculture and Robotics

Computer vision technologies are able to recognise crop rows based on shape, colour and location and steer the weeding device in the crop row to cut, uproot, burn or burry the weeds. The development of the autonomous robotic weeders with non chemical actuation can be further developed and commercialized in the near future. On a intermediate term, hyperspectral images will be developed for automated weed control. Techniques based on hyperspectral images will be more robust compared to shape recognition because they will function independently from the visible plant parts (Zhang et al. 2012).

To become a commercial success, equipment manufacturers will need to develop advanced machine-learning methods that characterize the spectral reflectance features of important crop and weed species over a wide range of growing environments.

Bioherbicides & biocontrol

In general there are three technological developments possible with respect to biologically based herbicides: (1) biochemical herbicides (microbial metabolites, plant-derived compounds, and certain naturally occurring chemicals), (2) microbial herbicides containing living or dead, plant-pathogenic or nonpathogenic microbes mixed in or not with their metabolites; and (3) genetically modified plants expressing pesticidal (herbicidal) substances (plant-incorporated protectants). It is anticipated that all of the above types of biologically based weed control methods can all play a role by 2050.

Data driven socio economic and knowledge change

There are at least four trends that may affect future information transfer relevant to weed management: wearable technology, contextualized learning, and big data. Wearable technology could serve to link growers to the most relevant information sources while they are in the field. Contextual learning is when information is provided in a way that individuals are able to construct meaning based on their own experiences.

"Big data" is a term for data sets so large or complex that traditional data-processing applications are inadequate. Data sets in agriculture are growing rapidly, in part because they are increasingly gathered by

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cheap and multiple information-sensing mobile devices, aerials (remote sensing), software logs, cameras, microphones, and wireless sensor networks. Most of these are already being used in agriculture, and their use can only be expected to grow. Accuracy in big data analysis may lead to more confident decision making, and better decisions can result in greater operational efficiency, cost reduction, and reduced risk. Challenges of big data include analysis, capture, data curation, searching, sharing, storage, transfer, visualization, querying, and information privacy.

Lack of changing human behaviour in weed management is an important issue that has been extensively considered in academia and industry (Jordan et al. 2016; Riemens et al. 2010). Accurate information on effective weed control strategies and herbicide use is available from many sources. In 2050, the spread of information and availability of knowledge has been delivered into mainstream will be significant. This will no longer be a reason for non adoption.
The above described technological and socio-economic barriers, requires the need for multidisciplinary/transdisciplinary teams of scientist, engineers, industry personnel, economist, ecologist, agronomists, sociologists, educators, and policy makers for the adoption, development and implementation of new approaches for non chemical weed management.

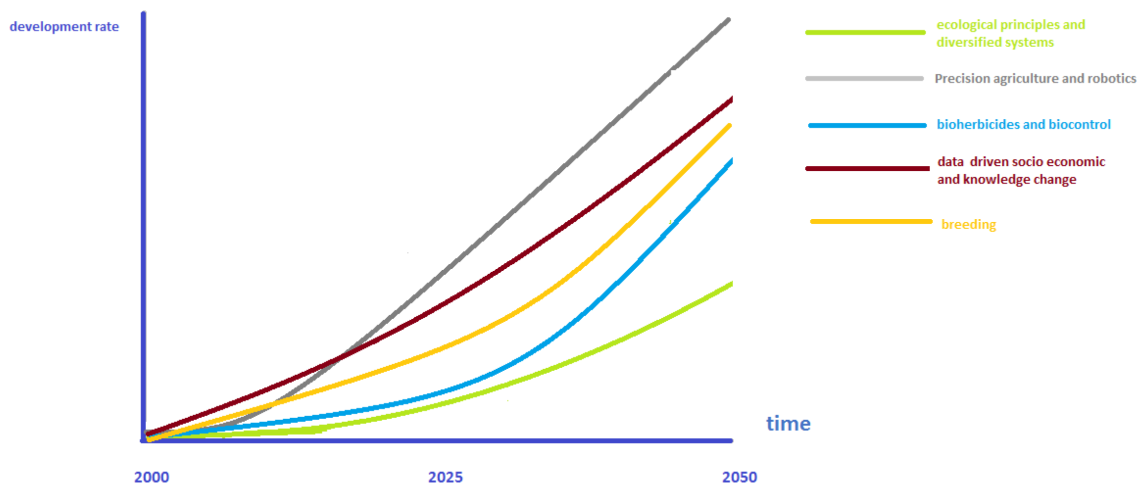

Figure 3. Depiction of the expected differences in development rate for the major areas for development for weed management in 2050. Lines indicate expected trends of development rate for the areas for development in 2050. These are solely meant for discussion purposes in this document.

References

Bastiaans et al. (2008) Focus on ecological weed management: what is hindering adoption? Weed Research 48, 481–491

Chikowo, R., Faloya, V., Petit, S., & Munier-Jolain, N. M. (2009). Integrated Weed Management systems allow reduced reliance on herbicides and long-term weed control. Agriculture, ecosystems & environment, 132(3), 237-242.

Eurostat Source: European Union, European Parliament. (2015), Draft Report on Technological solutions to sustainable agriculture in the EU (2015/2225(INI)

Heijting et al., (2007) Are weed patches stable in location? Application of an explicitly two-dimensional methodology Weed Research 47, 381–395

Jordan et al (2016), Transdisciplinary weed research: new leverage on challenging weed problems? Weed Research 56, 345-358

Kruidhof HM, Bastiaans L, Kropff MJ (2008). Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Weed Research 45 (6): 492-502.

Kolb LN, Gallandt ER, EB Mallory (2012), Impact of Spring Wheat Planting Density, Row Spacing, and Mechanical Weed Control on Yield, Grain Protein, and Economic Return in Maine. Weed Science 60 (2), pp. 244-253

Liebman et al. (2016) Ecologically sustainable weed management: How do we get from proof- of- concept to adoption? Ecological Applications, 26(5), 2016, pp. 1352–1369

Liebman, M., Gallandt, E.R. (1997). Many little hammers: ecological management of crop–weed interactions. In: Jackson, L.E. (Ed.), Ecology in Agriculture. Academic, San Diego, CA, pp. 291–343.

Liebmand & Staver (2001). Crop diversification for weed management. Book chapter in: Ecological Management of Agricultural weeds. Eds: Liebman, Mohler, Staver. Cambridge University Press. ISBN 0-511-03821-6

Melander, B., Cirujeda, A., and Jørgensen, M. H. (2003). Effects of inter-row hoeing and fertilizer placement on weed growth and yield of winter wheat. Weed Research 43:428–438

Melander B., Lattanzi B, Pannacci E (2015) Intelligent versus non-intelligent mechanical intra-row weed control in transplanted onion and cabbage Crop protection 72, 1-8.

Neve et al. (2018) Reviewing research priorities in weed ecology, evolution and management: a horizon scan. Weed Research,DOI: https://onlinelibrary.wiley.com/doi/epdf/10.1111/wre.12304

Oerke, (2006). Crop losses to pests. Journal of Agricultural Science 144, 31–43.

Peruzzi A. and Sartori L. (1997) *Guida alla scelta ed all'impiego delle attrezzature per la lavorazione del terreno* (Guide to the choice and the proper use of tillage operative machines). 255 pages. Edagricole, Bologna (Italy).

Riemens and Moonen (2018) https://iwmpraise.eu/wp-content/uploads/2018/06/WP1_IS_1_IWMPRAISE_eng.pdf

Westwood J.H., Charudattan R., Duke S.O.,Fennimore, S.A., Marrone, P, Slaugther D.C., Swanton, C., Zollinger, R. (2018). Weed Management in 2050: Perspectives on the Future of Weed Science. Weed Science 66:275–285. doi:10.1017/wsc.2017.78

Zhang et al (2012) Robust hyperspectral vision-based classification for multi-season weed mapping. ISPRS J Photogrammetry Remote Sensing 69:65–73

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