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AGRICULTURE & INNOVATION



EIP-AGRI Focus Group Non-chemical weed management in arable cropping systems

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1. Executive summary

Agriculture has become increasingly dependent on the use of herbicides and of pesticides, 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. At the same time, herbicides 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 these products. Developing and/or promoting non-chemical weed management (NCWM) techniques can reduce the risks linked to the use of herbicides. These management techniques range from preventive to curative strategies and be applied in both the organic and the conventional sectors.

The EIP-AGRI Focus Group on non-chemical weed management dealt with the question: "What are the challenges and opportunities for the implementation of non-chemical weed management practices in arable cropping systems in the EU?"

The Focus Group identified five key topics for non-chemical weed management in Europe:

Redesigning cropping systems

- ▶ Many factors determine the design of new cropping systems: types of crop diversification, new crop mixtures, new equipment and management needs, and changes in pests and diseases. **Integrated Weed Management strategies within diversified cropping systems need to consider applicability, efficacy, and reliability.**
- ▶ Conflicts may arise if cropping practices that are beneficial to weed management have adverse effects on other objectives such as energy consumption or CO₂ reduction.
- ▶ Research is needed to determine **appropriate cover crop species for greater weed suppression and limited phyto-toxicity in vegetable production systems**. More research is also needed on perennial weed responses to cover crops and conservation tillage systems.

Precision non-chemical weed control

- ▶ Increasing the **working rate** and reducing **power requirements** of non-chemical weed control tools and methods
- ▶ For narrow row crops, **determine the optimal bandwidth at a certain row spacing.**
- ▶ Adapt **intelligent intra-row weeding technologies to operate in direct-sown row crops.**
- ▶ **Individual plant recognition** is needed for more precision in site-specific weed management.
- ▶ **Large numbers of weed images** are needed to train deep learning classification networks, and training data need to be adapted to handle new crop and weed types.
- ▶ For **single plant weed control**, detection and control must be performed in a one-stage setup. Improving camera and detection systems to allow this is an important research need.
- ▶ Technology needs to be developed to **improve intra-row mechanical weed control.**
- ▶ More research effort should be devoted to 1) New sources of **bioherbicide** candidates; 2) Developing techniques for the cultural and genetic enhancement of bioherbicidal organisms; 3) **Consistent efficacy of bioherbicides in field conditions.**

Weed biology

- ▶ New research is needed in different countries and regions to understand: 1) the influence of different tillage systems on **weed seedbank dynamics** for different types of weeds; 2) how to encourage weed seed predation and decay; 3) the influence of soil microorganisms on the soil seedbank; 4) the effects of different crop rotations on the weed seedbank; 5) long-term experiments integrating preventive and direct methods; 6) simplifying methods to assess the soil seedbank: with bio-molecular probes; technology (x-ray) and automation (robots to collect soil samples).

Farmers' perceptions and decision making

- ▶ **Transdisciplinary weed research** to effectively manage challenging weed problems: these are better addressed in broad efforts to advance ecosystem sustainability, than as isolated problems.
- ▶ In NCWM, **economic costs** can mainly be related to the cost of tillage practices, including the costs of labour and cover crops, and indirect costs due to less effective weed control and yield loss. To develop weed control strategies that work on the farm, farmers need to be involved in their development and implementation. It is especially important that **farmers' risk perception and subsequent decision making on weed management** is integrated in the process.

Breeding for weed-suppressive and tolerant varieties/crops

- ▶ Exploring the potential of evolutionary breeding (composite cross-populations) to breed for competitiveness. This breeding approach can be adapted to the location where it is carried out.
- ▶ Breeding for short season varieties would help redesign cropping systems (see below).
- ▶ Breeding for allelopathic varieties: note that the allelopathic compounds are poisonous and may leave residues in the ground that are polluting, or they may have adverse effects on subsequent crops. This aspect needs to be addressed in research programmes.
- ▶ Overall, research should be devoted to better understanding traits and combination of traits for weed suppression and tolerance to weeds, both by individual crops and crop mixtures.

Finally, the Focus Group made some suggestions for local innovation projects, including EIP-AGRI Operational Groups:

- ▶ Working with arable farmers, researchers, industry and advisers in **co-design groups** to redesign cropping systems for non-chemical weed management to fit local conditions and market demands.
- ▶ Developing local strategies for a proper use of **cover crops**. This will include arable farmers and experts identifying the best, locally adapted species (and mixtures), sowing time, mowing/terminating method and time for the management of different cover crops.
- ▶ Developing local strategies for a proper use of **intercropping**. This will include local farmers and experts identifying the best, locally adapted crop combinations, fitting the local demands for market, mechanisation and agronomic conditions.
- ▶ Testing ways to **enhance biodiversity on arable fields**, involving existing local farmer networks to protect and enhance both functional biodiversity and biodiversity in arable systems.
- ▶ Involving local arable farmers in testing **equipment for precise weed management**. This enables farmers to test relatively expensive equipment under their own conditions. These tests should include evaluation in order to inform and share successful experiences with other farmers widely.
- ▶ Projects and demonstrations that **fully integrate direct physical control methods with the overall crop/weed management system**, particularly with cultural practices such as crop/cultivar choice, tillage operations, other agronomic practices.
- ▶ Participatory projects that focus on varieties or **crop mixtures with an increased tolerance or competition to weeds**.
- ▶ **Farmers' associations** have an important role in disseminating information and knowledge on NCWM. Trade journals are an important medium for disseminating information regarding NCWM. Other methods could include the Mayor's office, rural fairs and shows.
- ▶ Information can also be disseminated through mobile phones and **social media**. In this case, information can be spread not only fast but also widely. It is important to use these media as a source of **positive information** on farmers and NCWM.

2. Introduction

The Focus Group (FG) on non-chemical weed management was launched by the European Commission in 2018 as part of activities carried out under the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI).

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. Of all pesticides sold in the European Union in 2015, 33% were herbicides, haulm destructors and moss killers (Eurostat Source: European Union, European Parliament, Draft Report on Technological solutions to sustainable agriculture in the EU (2015/2225(INI)). At the same time, herbicides 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 these products by, among others, designing and implementing more integrated approaches for pest management that at the same time safeguard 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.

The Focus Group brought together 20 experts from all over the EU (see [annex A](#) for the list of members) with the purpose to:

- ▶ 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 the increase of carbon sequestration in soils, nutrient losses, soil degradation/erosion/compaction and biodiversity loss;
- ▶ 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.

3. Brief description of the process

The Focus Group met twice. The first meeting was held in Bucharest, Romania on 21-22 November 2019. In order to catalyse the discussion, a "starting paper" had been prepared beforehand by the coordinating expert, taking into account inputs from the 20 experts concerning the most relevant non-chemical weed management techniques within the different geographic regions of Europe.

At this first meeting, the group identified four core topics for further discussion, on:

- ▶ Crop diversification systems
- ▶ Field and soil management
- ▶ Use of weed-suppressive and tolerant varieties
- ▶ Targeted control

During the discussion, the following barriers for uptake or development of these non-chemical weed management tools and approaches were discussed:

- ▶ Environmental trade-off
- ▶ Economic (cost-effectiveness)
- ▶ Technological (labour intensity, feasibility)
- ▶ Individual (socio-cultural aspects)

At the end of the first meeting, five topics for "mini-papers" were identified for development by the Focus Group (complete list in [Annex B](#)):

- ▶ Precision agriculture
- ▶ Integration of tools / system design
- ▶ Weed biology / seedbanks / perennials / environmental trade-off
- ▶ Farmers' perceptions and decision making
- ▶ Breeding

The second meeting took place on 22-23 May 2019, in Oeiras, Portugal. At this meeting, the participants:

- ▶ presented drafts of the mini-papers;
- ▶ identified bottlenecks in the practical implementation of non-chemical weed management;
- ▶ gave recommendations and practical hints on how to overcome the bottlenecks;
- ▶ gave recommendations for further research and innovation activities to be proposed at European, national, and regional level.

Besides the meetings, the experts visited a local Operational Group to see and discuss non-chemical weed management in practice. Farmer Maria Francisca Azevedo Vasconcelos e Sousa was paid a visit. She participates in the Operational Group HortInf. This group is trying to find non-chemical alternatives to conventional weed management that could be used by Portuguese farmers. For 10 years Maria Francisca has primarily been cultivating potatoes, corn and barley in Golega, in the centre of Portugal. Perennial weeds like nutsedge (*Cyperus rotundus* and *Cyperus esculentus*) multiply through bulbs, rhizomes (rootstalks) and root sections and form a large problem at the farm. Traditional mechanical weeding methods lead to more rhizome sections that propagates these weeds instead of eliminating them. Maria Francisca: "At my farm we use chemicals for approximately 90% of the weed control. We are now looking for ways to use cover crops to suppress the nutsedge. Within the Operational Group, the farmers cooperate with a local researcher to find alternative measures for control."

4. State of play: non-chemical weed management

Integrated Weed Management

Weed control in current arable plant production systems in Europe is largely dependent on herbicides. Herbicides are easy to use and cost-effective compared to other existing alternatives. On the other hand, alternatives need to be combined to be as effective as herbicides. A possible side effect of herbicide use is the development of tolerance of weeds towards herbicides.

The 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.

According to the Focus Group experts, barriers preventing the adoption of IWM by farmers can be classified into biophysical, economical, technological, individual or socio-economical barriers.

The Focus Group experts considered that for weed control, an IWM approach should be put in place in order to obtain a reliable level of weed control. The experts identified opportunities and needs for development on the following topics:

1. Redesigning cropping systems for non-chemical weed management
2. Precision non-chemical weed management
3. Weed-suppressive and tolerant varieties and crops
4. Knowledge on the biology of weeds
5. Farmers' perceptions and decision making in relation to economic constraints and labour

1. Redesigning cropping systems for non-chemical weed management

Once weeds become established, their interactions with crops and landscapes are in a continuous state of flux, depending on environmental conditions and changes in weed control practices. Their long-term management is never static; it relies on a combination of techniques and strategies. Basic knowledge of the biology of the weeds and their population dynamics is required to prevent and manage resistant populations or control perennial weeds. As pointed out by Mortensen *et al.* (2000), 'we should go beyond the notion of regarding weeds as a problem that can be solved solely with herbicides to one that can be managed through a better design of cropping systems'.

The most intensive cropping systems are based on short crop rotations, meaning that major crops are frequently cultivated on the same land – e.g. wheat and maize – thereby reducing some positive agronomic services that could otherwise be provided by crop diversification. Simplification and high specialisation of cropping systems allows for the adaptation of problematic weed species to these systems, such as the development of resistant weed biotypes, the establishment of perennials and a general loss of biodiversity. Redesigning the cropping systems with the aim to make them more diversified would allow a better management of weeds with non-chemical weed management tools.

Good practices

Good practices that can be implemented today by farmers when they redesign their cropping systems for non-chemical weed control include: utilising crop rotations and cover crops, including intercropping, crop sowing patterns, sowing time adjustments and fertilisation.

- ▶ **Crop rotations**, including winter cover crops, and intercropping can influence the quantity and species of weeds present in spring-planted crops. Sustainable cropping systems require longer rotations, and requires a selection of a diversified mix of main and secondary crops to make sure that the soil remains covered over time (cover cropping) and space (intercropping). These cropping systems will vary depending on the specific pedo-climatic conditions within Europe.
- ▶ Crop rotation of annual and biannual or perennial crops, as well as *Poaceae* and *Fabaceae* (grains and beans) crop rotations can be effective both for weed management and for N fixation. These rotations should maintain a positive nitrogen balance and ensure a balance of cash crops and functional crops.
- ▶ When **cover crop** residues are left on soil surface as dead mulch or when they are ploughed and hence used as green manure, physical, chemical and biological effects occur that can reduce weed growth. The effects that cover crops have on weeds largely depend on cover crop species and management adapted to cash crop and weed community composition.
- ▶ Incorporating **allelopathic crops** to inhibit weed growth could also be considered. These crops are known to produce allelochemicals such as glucosinolates from *Brassicaceae* and benzoxazinoids from *Poaceae*; others have already been identified and used as bio-herbicides. However, there is a risk of phyto-toxicity.
- ▶ The crops may be seeded at the same time (mixed intercropping) or they may be seeded at different times (relay intercropping or pasture cropping). **Strip intercropping** is a production system where different crops are grown in wide strips (usually the width of a seeder) in the same field. The use of multiple crops that differ in traits such as sowing density, sowing type, canopy architecture, the selection for dominant weed species is reduced and the detrimental effects of these species prevented.
- ▶ **Intercropping systems** can be approached in two ways:
 - ▶ two or more crops grown together with the goal of maximising total yield from all intercrop components. Yield of each intercrop component is probably less than when it is grown as a sole crop, but the total yield is more than the sum of intercrop components grown separately;
 - ▶ one main crop with one or more secondary crops inter-seeded for weed suppression with the goal of maximising yield of the main crop.
- ▶ The **competitive ability of a weed** relative to a crop, depends largely on time of emergence. Usually early emerging weed plants are most competitive and more likely to survive and produce the most seed. For example, late-seeded spring crops and early-seeded fall crops generally have fewer *A. fatua* weeds than early-planted spring crops or late-planted fall crops. Since not all fields on a farm can be seeded at the same date, those fields with the worst weed infestation could be seeded last in spring, and earliest in fall. The disadvantage of delayed seeding can be reduced crop yield or quality.
- ▶ The **interval between harvesting one crop and drilling the next** is important, as a stale seed bed intervention can be used on weeds emerging after harvest. Delayed drilling increases the time available for weed control but it can reduce subsequent crop competitiveness, although an increased seed rate can help compensate the negative effect. The effectiveness of delayed drilling will depend on the germination period of the weeds (important knowledge of weed biology) and will be most effective for weeds with low dormancy and a clear autumn flush.
- ▶ While good **plant nutrition** is an important contributor to a vigorous, high-yielding crop, weed growth is also increased by nutrients. Getting nutrients to the crop and not to the weeds is therefore an important tool for producing a vigorous and competitive crop. Fertiliser placement and timing can be adjusted to increase the availability of nutrients to the crop and not to the weeds. In general, banding fertiliser below the soil surface, rather than broadcasting, helps seedlings get to the nutrients more quickly, increasing crop competitiveness. Different nutrients and fertiliser formulations require different treatment. For example, nitrogen is highly soluble in water and is rapidly moved away from its original placement. Therefore, banding

nitrogen is a short-term measure that is most effective when done as close to seeding as possible. That said, it is important to note that placing large amounts of nitrogen fertiliser close to the seed may damage the seed and thus reduce competitiveness. Adequate phosphorus levels are important for rapid early development. Unlike nitrogen, phosphate is not very water-soluble, and thus not very mobile. Therefore, phosphate fertiliser should be placed close to the seed.

Fail factors

- ▶ Fail factors related to the technical implementation of IWM cropping system changes concern applicability, efficacy, reliability and compatibility among curative weed control measures.
- ▶ The current process of specialisation of farmers, explained by the greater ease of acquiring technical control, the amortisation of agricultural equipment and the organisation of work with some crops in which the farmer specialises are constraints in diversifying systems.
- ▶ A lack of regional infrastructure to support changes in cropping systems, such as new crops and products, is another bottleneck. For instance, long rotations with permanent crops, like pastures, require local animal husbandry or industry (feed mills or pellets for alfalfa; dairy infrastructures).
- ▶ Mechanisation needs to be adapted to manage crops in intercropping systems; seeders, tillage instruments, harvesters. Interaction and potential trade-offs with other pests and diseases, nutrient management and value chain issues need to be addressed when a farmer changes to an intercropping system.
- ▶ The introduction of intercropping systems in certain regions such as the Mediterranean climate may be limited by the lack of precipitation and long periods of drought. Climate change will likely increase these challenges and lead to more extreme climatic events that will have a direct impact on agriculture.
- ▶ The current lack of breeding programmes and varieties bred for weed tolerance, weed suppressiveness or for performance in mixtures.

Success factors

- ▶ Farmers need to get sufficient support during the selection of appropriate crop rotations. Knowledge on the economic and agronomical consequences of the cropping sequence of their choice, and the impact of cover crops and intercropping choices need to be available. Farmers can then make an informed decision for IWM in relation to integrated cropping management practices and their financial and technological possibilities. It is important that this knowledge becomes available in local languages and is tailored to the local conditions in the Member States.
- ▶ Some tools with information on cover crops and species appropriate for living mulches are available throughout Europe. These tools can assist farmers in designing their cropping systems (OSCAR project, available at www.covercrops.eu and CATCHY cover crop project).
- ▶ Information on intercropping systems should become available, for instance through projects such as DIVERSIFY (www.plant-teams.eu) and REMIX (<https://www.remix-intercrops.eu/>).
- ▶ Co-designing cropping systems can aid the process. It requires farmers and advisers to work as a group during the redesign and implementation of cropping systems. Working this way allows the farmers of the group to discover their differences, learn from each other and implement relevant changes in their own system.

2. Precision non-chemical weed management

Agricultural operations are becoming increasingly more precise as technological developments enable improved data collection. Many start-up companies are developing in this fast-moving sector, to fill the gap in the market for hardware and software to enable improved observations, recognition, images, collection, analysis and eventually treatment of weeds. Improvements in weed control are being developed for both chemical and non-chemical applications and these operate differing scales of precision. As chemical weed control options are limited due to legislation, environmental concerns, chemical resistance and supply chain demands, non-chemical

options need to be developed in order for farming systems to work effectively. For some crops such as lettuce these are already developed and are becoming standard management practice. However, other crops and situations are far more challenging to develop. It is also recognised that non-chemical weed control can raise both environmental and economic concerns, such as the possible negative effects of mechanical weed control on soil quality, birds and beneficial insects and the increased costs of mechanisation and labour. Factors influencing adoption of non-chemical weed control by the farming community need to be acknowledged and addressed.

Good practices

The current availability of precision non-chemical weed management options is shown in the table below. Compared to precise chemical weed control, the availability of precise non-chemical weed management solutions is limited.

Table: Availability of precision non-chemical weed management options

	Chemical options	Non-chemical options
Farm	Easily achieved	Easily achieved
Field	The normal management is now facing challenges related to chemical resistance, product withdrawal and environmental pressures.	Used on organic farms or where product specification or challenges in chemical control lead to predominantly mechanical removal techniques.
Site-specific	Achievable through either satellite, drone, manual scouting mapping and zoned spray applications.	Achievable through either satellite, drone, manual scouting mapping and then selective use of machinery which is generally restricted by machinery width.
Plant-specific	A range of systems are under development but few are commercially available.	Currently predominantly achieved through point treatment but mainly through hand weeding.
Leaf-specific	Under development but not available commercially	None available

- ▶ Narrow-spaced crops are those established at high seed rates and small distances between crop plants within the row. Cereals, rapeseed, beans, peas etc. are the most common agricultural crops grown in narrow rows. These crops are normally grown in crop stands with a row distance of around 12 cm. Weed harrowing can be done at high work rates using 12 m working widths (6 m on each side of the tractor) and driving speeds up to 12 km per hour. When the row distance increases to 20 cm then inter-row hoeing with automatic steering systems is a growing weeding technique in narrow-spaced crops. Hoeing is more aggressive than weed harrowing, and especially tap-rooted weed species are more efficiently controlled by hoe blades. Steering is accomplished with cameras and/or GPS-systems that allow the hoe blades to operate close to the crop plants without damaging them.
- ▶ The crop competition is also important in hoed cropping systems for the suppression of weeds in the row, as these weeds are not directly impacted by the hoe blades. Spring tines and finger wheels working in the row can be used in row crops, such as maize and rapeseed, but are more difficult to apply in crops that have dense stands in the row.
- ▶ Cutting the weed in the crop with knives is another option to influence weed growth in narrow row crops. It has been tested in pots and in field trials. The knives can cut weeds with a stem that is thicker than the

leaves of the crop. The technique was tested on farms at wide crop row spacing but the denser the crop in the row, the more difficult the selection of weeds from the crop.

- ▶ Intra-row weeds in row crops pose unique challenges due to their proximity to the crop. For most row crops, it is essential that robotic intra-row weeding machines are able to operate as closely to the crop plants as possible, to minimise yield loss and the need to remove any surviving weeds by hand. Mechanical and thermal weeding devices are most effective when the weeds are small and juvenile; efficacy declines as weeds become larger and better established. While weeds are most vulnerable when small in size, the same is equally true for the establishing crop. Balancing efficacy of weeding while minimising crop injury is, therefore, another important consideration, and selectivity of weed management tactics must be considered while implementing direct, post-emergence treatments.
- ▶ In a transplanted crop, robotic weeders fitted with vision-guidance systems are capable of cultivating between crop plants within the row without reducing crop stands or yields. Currently, four such weeders are available for practical use on the European market: *Robovator* (www.visionweeding.com), *Robocrop* (www.garford.com), *Steketee IC* (www.steketee.com) and *Ferrari Remoweed* (www.ferraricostruzioni.com). The *Ferrari Remoweed* is very new to the market and uses infrared light sensors to detect crop plants, while the other three machines detect crop plants using cameras. All of the machines mentioned above are best suited for use in crop stands where a clear crop-weed distinction is present.
- ▶ Precise weed management at site or plant level requires accurate weed sensing and targeting. Image capture and analysis are frequently used techniques for weed mapping and weed sensing. However, their performance can be influenced significantly by the local conditions. Alternatively, farmers can use a hand-held GPS receiver to geo-locate weed patches manually. Technology start-ups and companies increasingly offer cloud-based mapping services using images that are captured via satellites, and such images are now free via the EU Sentinel satellite services. Others use manned aircraft, unmanned aerial vehicles (UAVs) or ground vehicles. Each approach has advantages and disadvantages.
- ▶ The technology needed for weed mapping and site-specific weed management (SSWM) includes an in-cab computer and software, a geo-referenced weed map interpreted into a treatment map, equipment capable of varying the SSWM method across the field in real time and a global navigation satellite system (GNSS). The GNSS is freely available through satellite constellations such as the US-funded GPS, EGNOS (European Geostationary Navigation Overlay Service for GPS), the Russian-funded GLONASS and the European Galileo system. More precise geo-referencing is achievable using localisation of signals for example to a base station. Farm machinery must be loaded with the prescription maps which determine exactly where in the field to apply non-chemical weed management.

Success and fail factors

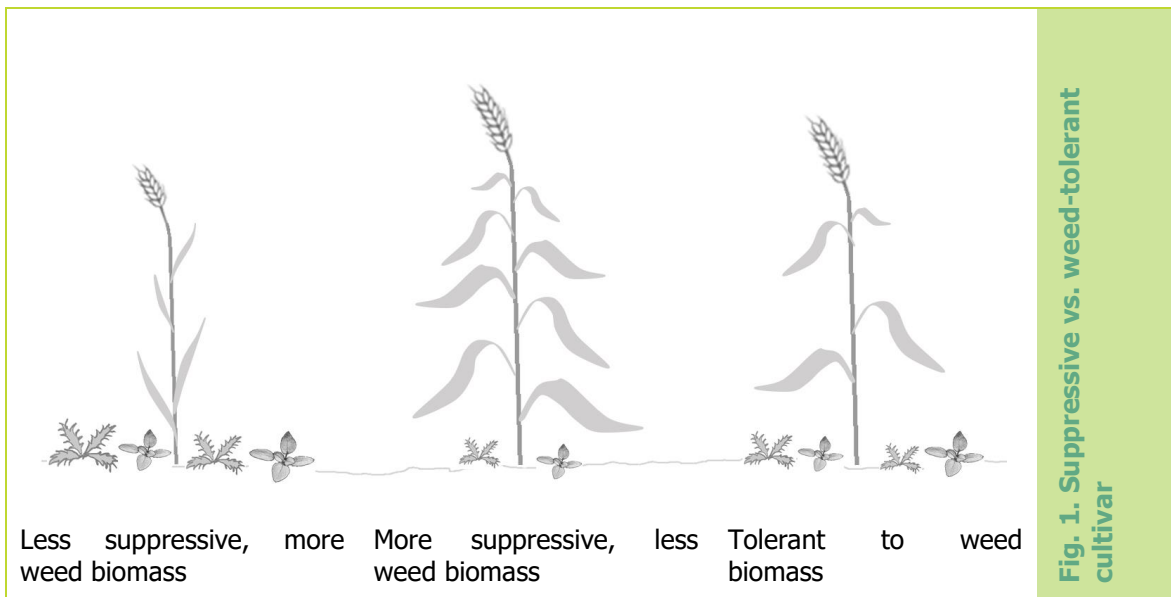
- ▶ In cropping systems based on inter-row hoeing, the crucial question is which inter-row distance to use. Several investigations around optimal row distance in different crops have been done and outcomes vary. Important is that under local conditions, and taking into account important factors such as fertilisation, farmers test widening row distances combined with increasing seeding densities to get experience with hoeing narrow-spaced crops.
- ▶ It would be helpful that alternative options for weed control within the rows of narrow-spaced crops are developed. It might be possible to place the seeds in a grid-like pattern that would make it possible to do intra-row mechanical weeding. Other options might be relevant but more research is needed in this domain to find practical solutions for precise weed management in narrow row crops.
- ▶ Precise weeding has many benefits over the non-precise tools, such as more hours of operation (operation is even possible at night time), easier to implement in practice, less risk of crop injury, only one operator is needed, more flexibility in treatment timing in relation to weed growth stage, and it is the only alternative to removing weeds by hand in lettuce.

- ▶ There is a general consensus in the industry, among advisory bodies and in the research community that the adaptation of intelligent intra-row weeding technologies to operate in direct-sown row crops and not just in transplanted ones, would constitute a major step forward.
- ▶ Costs and the ease of using chemical herbicides is often preferred by growers compared to mechanical solutions. Tractor-mounted implements for weed management have, therefore, disappeared almost completely except in high value crops or organic farming. Chemical crop protection is, however, under more and more socio-environmental and scientific pressure. In particular, the increasing development of organic farming, also promoted by policy developments, such as the [European Commission`s Green Deal](#), leads to a new focus on mechanical weed management solutions, which are able to compete financially with the use of herbicides. This requires new technical solutions on both tractors and implements.
- ▶ In general, farmers do not have the right machinery to apply precise weed management for all their crops. There is also a risk aversion associated with the real possibility that a bird or a deer or a piece of farm machinery or a dog walker or even an agronomist might have moved a single viable seed from a dense patch to a 'clean' part of the field. Uncertainty about the stability of weed patches may also be a factor if the weed maps are based on weeds detected in a previous crop. Near real-time sensing at early crop growth stages using UAVs may alleviate many concerns, but the inability to detect individual weed plants may still make farmers unwilling to invest or take the risk.
- ▶ The economic benefits of precise non-chemical weed management need to be demonstrated before farmers will adopt and implement these technologies. It is suggested that economic analyses should not only predict the expected costs and benefits, but they should evaluate the probability of making *more* profit.
- ▶ The trade-off between (non-chemical) mechanical weeding and other crop management objectives such as the preservation or increase of soil organic matter, which is pursued with no-till practices, may hamper the adoption of mechanical weed management.

3. Weed-suppressive and tolerant varieties and crops

Using the competitiveness of a crop either for being weed-suppressive or weed-tolerant is a relevant way to reduce the need for more invasive types of weed management. Herbicide resistance has been the major focus of many breeding programmes, at least at a global scale. The introduction of herbicide-resistant crops has resulted in an increased global dependence on herbicides in arable systems. A shift towards breeding programmes selecting for weed-suppressive genotypes can potentially reduce the need for weed management and direct weed control without the negative side effects of herbicides on the environment. 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 programmes that help reduce the need for weed control with herbicides.

A crop cultivar that reduces the fitness of a weed or other plant is called suppressive, a crop cultivar that does not react with yield loss – or only to a small degree – when faced with competition from weeds (or other crop plants) is called tolerant, see fig. 1. If a weed is suppressed by a crop, it will have reduced seed or other propagule production, which will aid the long-term management of the weed. This might not be the case if the crop is tolerant but does not suppress weeds. The value of the use of tolerant crops needs to be determined for each crop rotation.



Good practices, success and fail factors

There are many possibilities for breeding for increased competitiveness in crops. However, traditionally breeding has mainly been focused on yield, quality and disease resistance. It may be difficult to change this towards breeding for increased competitiveness, due to the relatively small economic return for breeders. With an increasing demand for competitive crops this may change in the future. Taking into account the results mentioned above, it could be possible to include at least an evaluation of the competitive characteristics of varieties in breeding programmes, so that farmers could have this information included in their choice of variety. For example, an organic farmer may find it more important to have a competitive species (because it may yield more under conditions with more weeds) rather than varieties tested under weed-free conditions where herbicide has been applied.

Table 1. Combination of breeding goals with other cultural and mechanical weed control methods

To use	Breed for		Effect on		Trade-offs	
	Suppressiveness	Tolerance	Yield	Reduced weeds	Next season	
High seed rates		X	X	X		€, nutrients, disease
<i>Seeding pattern:</i>						
<i>Row width narrow</i>		X	X	X		
<i>Row width wide</i>	X		X	*		

Mixtures		x	X	X		maturity
Intercropping		x	X	X		
Cover/catch crops	X	X	X	X		€
Sowing time			X	X		Soil conditions
<i>Short season:</i>						
<i>False seed bed</i>			X	x		
<i>Early harvest</i>			X		x	
Allelopathy				x	x	residues

* only if mechanical weed control is efficient cover crops or tillage to reduce weeds.

4. Knowledge on weed biology

One of the main challenges of today's agriculture is to design resilient crop systems that can self-regulate a large proportion of bio-aggressors such as weeds. The weed flora found in a crop is formed by an assortment of species that have developed survival strategies involving different functional traits and response traits. The great challenge of controlling weeds without herbicides includes relying on the knowledge about the response of species to agronomic practices (mechanical weed control included). This knowledge can help build preventive strategies for weed control before implementing weeding practices.

The behaviour of a species can be defined by five main parameters: the biological type, the emergence timing, the emergence mode, the quantity of seeds produced and the duration of conservation of seeds in the soil.

Three categories of species can be distinguished. For each of these categories, the approach for weed management differs:

- **annual species** that reproduce mostly by seed and of which the life cycle is less than one year (or one cropping season). They represent more than 80% of weeds in traditional arable and vegetable cropping systems;
- **biannual and multiannual species** that survive for one or more years but eventually disappear after one or more cycles of seed production. In field crops, they often behave like annuals because they are regularly destroyed by agronomic practices;
- **perennial species** multiply and survive over the years indefinitely by their vegetative system, thanks to various specialised organs (underground stems, creeping aerial stems rooting at nodes, aerial stems born from root buds, tuberised stems or roots loaded with reserves). Many perennial species have also retained the ability to produce seeds, providing them with a great adaptability.

Good practices

- ▶ Identifying the type of species that is dominant in the field and determining the weed strategy to control this group of weeds.
- ▶ For perennial species it is in general **not** beneficial to reduce the level of soil disturbance: ploughing, mechanical weed control and a large percentage of annual crops all help control perennial weeds. Detailed information on the biology of the species is useful to determine the exact timing of the application of treatments, the cropping sequence and the type of cultivation that are needed to control the perennial weed species in the field.
- ▶ Determining the time of emergence of the dominant species in the field. Some species are predominantly spring-emerging, others emerge in fall, and some are indifferent: they can germinate and emerge during the whole year. Alternating winter crops and spring crops, and crop diversification bring greater diversity of weed flora because each crop is always accompanied by its floristic group. The initial rotation can be modified to optimise the system to the conditions of the cultural year, but it must always respect the basic principles of alternation and diversity.
- ▶ Preventing the production of weed seeds: either by hand weeding or by using a machine that collects seeds during the harvest.
- ▶ Not all viable seeds buried in the soil will provide a seedling. A significant quantity will disappear either by senescence or by predation or parasitism. In addition, not all germinated seeds necessarily lead to an emerged plantlet: the crust of soils or a large burial depth are obstacles to plant emergence. In the absence of any re-infestation, a decrease in the seed stock is observed. This decline, usually expressed as a percentage of the initial stock, is called the Seed Annual Decrease Rate (SADR). Specific to each species, considering this criterion is essential to understand weed emergence dynamics in crops. Weed species can be grouped according to their uneven reaction to burial. Tillage is effective against species with high declines per year, like most grasses. It must be closely combined with crop succession to lay the pillars of an integrated and strong preventive management. Ploughing every 3 or 4 years is more than enough in a normal situation. When done too frequently, the use of ploughing risks cancelling its benefits by distributing the seeds throughout the worked depth. This is all the more true for species with a rather persistent stock: ploughing should be spaced out in time to let the cleaning power of the soil act.

Success and fail factors

- ▶ Biological data on weeds encountered in arable crops are rare and dispersed. They are difficult and expensive to obtain and until recently they did not seem indispensable, considering the available chemical weeding solutions. Some trait databases exist: <http://www.infloweb.fr> provides a wealth of information on the biology and chemical and non-chemical control methods of some 40 species; <https://onlinelibrary.wiley.com/doi/10.1111/wre.12126> combines a weed traits database with a population dynamics model to predict shifts in weed communities. These databases should be enhanced to form a solid base for breeding programmes and decision support systems.
- ▶ At the moment there is no return on investments for companies to invest in this type of knowledge. However, the information is useful for the farming community.

5. Farmers' perceptions and decision making in relation to economic constraints and labour

Farmers and society at large share concerns about health and environmental issues related to herbicide use, particularly raised after several inquiries into glyphosate. Environmental issues such as herbicide resistance of weed populations are a major concern for farmers. Looking at the literature on farmers' perceptions and decision making and weed management, it emerges that the main factor pushing farmers to adopt diverse weed management strategies is herbicide resistance. It is worth noting that research on drivers of farmers' choices on weed management is relatively recent.

EU legislation may limit the number of herbicide active ingredients that farmers can use. Availability of herbicide is also restricted by the lack of development of new herbicide compounds in the last 30 years. Nonetheless farmers' techno-optimism (i.e., the belief that new herbicide chemistry will be available in the future), is still a factor limiting the adoption of NCWM strategies.

Success factors affecting the adoption of non-chemical weed management techniques/practices by farmers

► Economics

Low financial margins predispose the farmer to adopt new techniques if the customer is prepared to pay a worthwhile premium.

► Potential benefits of weeds

Some farmers are aware that weeds have benefits, though there is a need to keep their presence in the field balanced. In other words, there can be acceptable levels of weeds. Some of the benefits that weeds may bring include: an improved soil structure due to the diverse rooting systems; the increased plant diversity helping to reduce some diseases (although they can be detrimental to others); weeds create a ground cover when crops are removed (this could be looked at as a cheap way of establishing a cover crop without having to use expensive seed and with minimal labour); weeds can give farmers information about their soil, and can protect soil against erosion.

► Enhanced biodiversity

The presence of a diverse weed flora can provide other ecosystem services in addition to food production. For instance, weeds can provide food and shelter to biota including insects that serve as pollinators or natural enemies. Insects in turn act as a food source for birds. The rooting diversity of different weeds also has positive impacts on soil biodiversity.

► Some of the observed farmers' motivations for change include:

- Weed resistance is beginning to make some herbicides ineffective.
- Some farmers feel unease about the growing public awareness of chemical residues in the food, the detrimental effect of herbicides on soil microorganisms, insects, human health and water quality. At present, in some parts of Europe, farmers are portrayed in a very negative manner on some media platforms. It is uncertain whether this will trigger adoption of non-chemical weed management techniques by farmers, in particular if there are no cost-effective alternatives at their disposal.
- An increasing number of farmers feel that the practice of pre-harvest spraying is unnecessary and has induced consumer worries on herbicides.
- Regulations restricting the use of certain active ingredients stimulate farmers to use alternatives.

Fail factors affecting the adoption of non-chemical weed management techniques/practices by farmers

► NCWM strategies based on ecological weed management principles show that they are more weather-dependent than herbicides. The integration of alternative strategies is difficult to manage, knowledge-intensive and site-specific. Moreover, farmers do not feel comfortable with changing an entire set of practices because of the uncertainty related to its benefits and trade-offs. In 2008 Bastiaans et al. highlighted that "quantitative estimates are also the only way to establish the true costs of ecological weed management practices". A comprehensive quantitative estimate of weed control trade-offs is very difficult to achieve and is still lacking. The cost-effectiveness of innovative technologies such as 'precision agriculture' is not yet clear to farmers. This uncertainty hinders the adoption of technologies such as robotics for weed control.

► Farmers' economic considerations generally focus on the short term. Ecologically-based NCWM strategies are associated with higher costs in the short term but greater environmental benefits in the long term (including overcoming herbicide resistance and health benefits). A long-term perspective is however not

appealing, unless payments compensate for the short-term revenue reduction. Moreover, long-term benefits need to be communicated more clearly to engage farmers.

- ▶ Fear of change. Chemical weed control is the tried and tested method and any change is a risk. The idea of making changes here (e.g. not using herbicides) can trigger anxiety, fear of not achieving the results, and also whether enough income can be generated from the farm. This does not usually affect one single person, but the whole co-operating family: in the field of agriculture, the workplace and family are strongly linked. Farms are traditionally passed on from generation to generation. That's why the fear of failure weighs heavily on the responsible people. Often, there is a feeling of powerlessness to confront established structures. Thus it requires courage to go new or unfamiliar ways for fear of being side-lined and fear of failure.
- ▶ Social reputation. Farmers know each other and observe other farmers' management practices very closely. Some land owners do not like to see their property with weeds. But pioneer farmers can have a strong positive impact on their peers.
- ▶ Public opinion. Whereas farmers feel a sense of disquiet about how consumers regard chemicals used in agriculture, they also feel there is no alternative unless they convert to organic and receive a price premium. Most conventional farmers are not prepared to do this because they think it would result in reduced yields and it does not sit well for them that organic farming is still demanded by a segment of consumers.
- ▶ NCWM requires an investment in expensive equipment or in many different tools instead of one sprayer. Sharing machinery between farmers would lower the capital costs making it possible to have the use of a machine that they otherwise could not afford. However, it is not practised extensively in Europe because of transportation issues between farmers, cost of legal agreements, damage to machinery and delays at planting or harvesting. Contracting and hiring of machines is a more popular approach.
- ▶ The dependence of farmers on chemical weed control, caused and/or influenced by the following factors:
 - Farmers cannot see an alternative while their margins are tight or non-existent. Alternatives can be labour-consuming, knowledge-intensive and an expensive capital cost.
 - Some of the alternatives involve inter-row cultivations which results in extra diesel consumption, compaction and may be detrimental to the ecology.
 - Since it would not be interesting for farmers to adopt alternative weed control without a premium price or financial incentive, the farmer only has two choices at present. That is to farm conventionally with chemical weed control or go organic. The organic alternative does not appeal to everyone because of the yield reduction and the level of weeds on some long-term organic farms. However, under the future EU Common Agricultural Policy eco-schemes, EU Member States will have the possibility to support agro-ecological practices, of which organic farming is an example.
 - The farming community holds the belief that without glyphosate there would be considerable disruption. NCWM would need to make major developments before it could be considered as a realistic alternative, without a financial incentive.
 - If NCWM results in reduced yields, it is unlikely to receive political support especially in countries that are not self-sufficient in food.
 - There is an opinion held amongst some conventional farmers that no weeds should be tolerated; they practise a zero tolerance approach. They feel that if any weeds are present they will seed and create an ever increasing problem, (one year seeds is seven years weeds). Also weeds reduce machinery output and increase crop moisture at harvesting.
 - In order to create a diverse rotation in the farming system it is necessary to have the markets established for any additional crops. The change has to be market-led otherwise it will not be sustainable.

Because actions are traditionally anchored, it is difficult to change them. For this reason new ideas and results from research have to be effectively communicated within the farming sector in order to promote the uptake of these practices. Even if changes have already been introduced, time is required until appropriate processes are firmly established.

5. What can we do? Recommendations:

a. Ideas for local innovation projects, including EIP-AGRI Operational Groups

The proposed topics and contents for Operational Groups, recommended by the experts are:

- ▶ Working with arable farmers, researchers, industry and advisers in **co-design groups**. Redesigning their cropping systems for NCWM in a group of peers gives farmers a great opportunity to learn from peers, under guidance of an expert. The designs can be implemented on local farms, fitting local conditions and market demands.
- ▶ Developing local strategies for a proper use of **cover crops**. This will include arable farmers and experts identifying the best, locally adapted species (and mixtures), sowing time, mowing/terminating method and time for management of different cover crops.
- ▶ Developing local strategies for a proper use of **intercropping**. This will include local farmers and experts identifying the best, locally adapted crop combinations, fitting the local demands for market, mechanisation and agronomic boundaries.
- ▶ Testing ways **to enhance weed diversity on arable fields**, through the activation of existing local farmer networks to protect and enhance both functional biodiversity and biodiversity in arable systems. The project could list locally adapted good practices to maintain or increase biodiversity in arable crops.
- ▶ Involving local arable farmers in testing **equipment for precise weed management**. This enables farmers to test relatively expensive equipment under their own conditions. The equipment could range from full field non-chemical weed control tools to precision agriculture tools to enable site-specific weed management. These tests should include evaluation in order to inform and share successful experiences with other farmers widely. Successful experiences should be shared widely.
- ▶ Projects and demonstrations that **fully integrate direct physical control methods with the overall crop/weed management system** particularly with cultural practices such as crop/cultivar choice, tillage operations, other agronomic practices.
- ▶ Participatory projects that focus on varieties or crop mixtures with an increased tolerance or competition to weeds.

b. Research needs from practice

Tools and tactics

- ▶ Increasing the **working rate** and reducing **power requirements** of non-chemical weed control tools and methods, such as electrocution, laser cutting or damaging, precision flaming, defoliation by cutting, mechanical damaging, foam application, pushing or punching the weed into the ground, or pulling it.
- ▶ For narrow row crops, **determining the optimal bandwidth at a certain row spacing in different crops both in terms of yield responses and weed suppression of intra-row weeds**. At present, suppression from the crop seems to be the only option for minimising the insurgence of intra-row weeds. Recent studies have shown that widening the row (band sowing) can improve the suppression of intra-row weeds as compared with sowing in lines. The wider the row distance the more important it is to widen the intra-row space as well. In organically grown spring wheat, a 7 cm bandwidth gave 4 % greater yield at 25 cm row spacing than normal bandwidth (2 cm). At a 50 cm row distance in organically grown spring wheat and winter wheat, a 12 cm-wide band gave 6 % greater yield compared with normal 2 cm-wide rows and 50 cm inter-row spacing.
- ▶ There is a general consensus in the industry, among advisory bodies and in the research community that the adaptation of **intelligent intra-row weeding technologies to operate in direct-sown row crops** and not just in transplanted ones, would constitute a major step forward.

Several issues need to be resolved. For example, there is a trade-off between reducing the operational distance between the weeding tool and the crop and the yield benefits associated with weeding a greater area of the soil's surface. There are also trade-offs with the management of soil organic matter. As robotic hoes and flame weeders are developed to function in direct-sown crops, it will be essential to quantify their efficacy and the likely damage to the crop at different growth stages, for different frequencies of weeding, and at different working distances from the crop plants.

- ▶ **Individual plant recognition** for more precision would be a prerequisite for site-specific weed management. For the purpose of single plant detection and non-chemical weed control several aspects need to be distinguished. When control of weeds is required with minimal inputs of energy, and in a sustainable way not disturbing more soil than necessary, only individual weed plant recognition is a good solution. Detection of crop plants is not enough for effective and efficient weed control with minimal inputs of energy, as large bare soil areas will be treated or disturbed, having negative impacts on the growth conditions of the crop. One can think of excessive evaporation, loss of water or germination of new weed seeds due to soil disturbance effects. For the purpose of single weed plant identification and localisation, several techniques are available. As of 2019 large databases are available containing images of weed species in several growth stages. These databases can be used to train real-time deep learning neural networks. For training deep learning classification networks, **large numbers of weed example images** are necessary, and adaptation of training data is necessary to handle new crop and weed types during the season and between seasons.
- ▶ For **single plant weed control**, detection and control must be performed in a one-stage setup. Improving camera and detection systems is an important research need. Using these machine vision and camera techniques, single weed plants can be identified. Of course depending on the growth stage, detection results are changing and improving for larger growth stages of weeds. To effectively control the weeds, not only the weed location and weed species is required, also weed growth stage and leaf biomass would be needed. One can imagine that a small weed requires less energy or mechanical damage to be controlled compared to a larger weed. A detection system would ideally also estimate the crop growth stage as well, to properly set thresholds on allowed crop damage, and to estimate and adjust the weed control method to stay within acceptable limits. With current 2019 camera technologies weed plants can be detected with the precision of up to one square mm. This means that contours of leaves can be identified, as well as centres of plants and total leaf area of weeds. It is however still challenging to find positions where the weed is actually going into the soil. So the root positions are mostly unknown from camera detection results. Some of the control methods would preferably have this root position information as well to better target the control method. Current camera-based detection systems, either regular colour RGB cameras or including hyperspectral cameras, have a resolution of approximately 1 square millimetre to assess the weed species and the weed location. For most camera systems for weed detection that are on the market, the **actuator is not directly in the camera's field of view**. Therefore the accuracy of the system is influenced by the machine's movement between detection and control.
- ▶ Technology advancements to **improve intra-row mechanical weed control** such as high-tech torsion/finger weeders, harrows, hoes and flame weeders to get closer to the crop plant without inflicting damage.
- ▶ More research effort should be devoted to 1) New sources of **bioherbicide** candidates; 2) Developing techniques for the cultural and genetic enhancement of bioherbicidal organisms; 3) Increasing knowledge about the mechanisms underlying these effects. It is important to achieve consistent efficacy with biocontrol agents, as well as to evaluate potential impacts on human and ecosystem health; 4) Evaluating bioherbicides in field trials in different crops and different regions. At present, bioherbicide efficiency is usually lower than that obtainable with chemical control. Bioherbicides should be assessed concurrently with other weed management techniques in cropping system experiments. A better understanding of the ecology of field-applied antagonists may lead to an optimisation of formulations, and time and mode of application, with beneficial effects on the level of protection obtainable; 5) Developing and evaluating formulations to improve performance and standardisation of selected bioherbicides. Although there is a considerable number of candidate species that have been considered for this purpose, the major challenge to successful implementation of this strategy is the development of techniques to maintain **consistent efficacy in field conditions**.

In this context, the Focus Group experts also mentioned constraints to be addressed to **improve bioherbicide development and implementation**, which are not research needs: a) Strict Legislation. The existing legislation concerning authorisation should be simplified and be more flexible, taking in account that the concept of bioherbicides is broad; b) Improving quality and sufficient quantities of materials for affordable prices and; c) Better cooperation should be established between research and bioherbicides manufacturers to offer those research results to practice.

Breeding for weed-suppressive and tolerant varieties/crops

- ▶ There is a range of crop traits that are associated with suppressive capacity, tolerance or both, often defined together as competitiveness. Tolerance can be measured as the percentage of yield reduction under weedy conditions, whereas suppressiveness can be measured as relative weed biomass in the presence of different cultivars. **Research has indicated that a screening programme for crop variety suppressiveness would ideally be based on only a few, non-destructive measurements** of key growth traits, such as:
 - ratio vegetation index and leaf area index, leaf angle (planophile leaf inclination), time of development, plant height and tolerance to shading, early vigour or early leaf area development, tillering (rate of tillering and final tiller number), canopy height (culm length), early height growth-rate, canopy architecture, root length/density and other root associated traits, lodging, nutrient and water efficiency.
- ▶ Exploring the potential of evolutionary breeding (composite cross-populations) to breed for competitiveness amongst other goals. This type of breeding would be very well adapted to the location at which it is carried out. However, farm-saved seed gives higher risk of seed-borne diseases. There are also legal issues about seed certification.
- ▶ Breeding for short season varieties; these would give the possibility to include sowing date, stale seed bed, different weeding/tillage techniques, and would help redesign cropping systems (see below).
- ▶ Breeding for allelopathic varieties. While some species excrete compounds from the roots during the growth of the crop, others release compounds after termination of the crop. However, the allelopathic compounds are poisonous and may leave residues in the ground that are polluting. This aspect needs to be addressed in the research programmes. The allelopathic effect may also give adverse effects on the subsequent crops with lower germination, a factor that needs to be taken into account in the cropping system designs.
 - Overall, research should be devoted to better understanding traits and the combination of traits for weed suppression and tolerance to weeds, both by individual crops and crop mixtures.

Redesigning cropping systems

- ▶ There are many factors determining the design of new cropping systems. For instance, spatial and temporal diversification of systems leads to different crop mixtures. These generally require new types of equipment and management. Pests and diseases may also change. In particular, the **issues related to the technical implementation of IWM strategies within diversified cropping systems concern applicability, efficacy, and reliability**.
- ▶ Other issues include conflicts that arise if cropping practices beneficial to weed management have adverse effects on other objectives such as energy consumption or CO₂ reduction.
- ▶ **Transdisciplinary weed research (TWR)** is a promising path to more effective management of challenging weed problems. TWR is defined as an integrated process of inquiry and action that addresses complex weed problems in the context of broader efforts to improve economic, environmental and social aspects of ecosystem sustainability. The fundamental rationale for TWR is that many challenging weed problems (e.g. herbicide resistance, extensive plant invasions in natural areas) are better addressed systemically, as a part of broad-based efforts to advance ecosystem sustainability, rather than as isolated problems.

- ▶ In NCWM, **economic costs** can mainly be related to the cost of tillage practices, which includes higher labour costs, cost of cover crops and the indirect costs related to less effective weed control and yield loss due to changes in crop rotation. Weather conditions are a major constraint for the adoption of NCWM strategies such as delayed winter cereal drilling. To develop weed control strategies that work on the farm, farmers need to be involved in their development and implementation. It is especially important that **farmers' risk perception and subsequent decision making on weed management** is integrated in the process.
- ▶ Limited information is available on benefits of cover cropping for weed control in vegetable systems, therefore, research is needed to determine **appropriate cover crop species for greater weed suppression and limited phyto-toxicity in vegetable production systems**. More research is also needed on perennial weed responses to cover crops and conservation tillage systems.

Weed biology

- ▶ New research is needed in different countries and regions to understand: 1) the influence of different tillage systems on **weed seedbank dynamics** for different type of weeds; 2) how to encourage weed seed predation and decay; 3) the influence of soil microorganisms on the soil seedbank; 4) the effects of different crop rotations on the weed seedbank; 5) long-term experiments with integration of preventive and direct methods; 6) the simplification of methods to assess the soil seedbank: with bio-molecular probes; technology (x-ray) and automation (robots to collect soil samples).

Other recommendations, including improving take up

- ▶ Farmers have only recently become aware of the reduced biodiversity in Europe. The restoration of a diverse natural weed flora could contribute to the **restoration of biodiversity**, since weeds can provide shelter and food to other biota.
- ▶ Introducing herbicide use taxation, as promoted by the Danish Ministry of the Environment in 2012, could force farmers to reduce herbicide use but could also promote the use of cheaper herbicides, which could lead to herbicide resistance. When the **Common Agricultural Policy (CAP)** has offered financial returns for adopting environmental tasks, farmers have demonstrated a quick uptake to put these measures into action. However, at present the CAP has no holistic approach to encourage farmers to reduce pesticide use (ref: Pan European analysis 'Why the CAP is broken on pesticide use reduction'). For the adoption of NCWM it will probably require both carrot and stick. Ideally, the CAP would provide incentives, with the large retailers playing a significant role in shifting farmers' perceptions and decision making following consumer demand.
- ▶ Organising social events to foster relationship building among farmers can foster co-operation. For successful weed control and for reducing management costs, **farmers' co-operation** at field level is key. Farmers learn well from their peers. Discussion groups which are overseen by a facilitator have proven to be a satisfactory method. If a farmer adopts a new practice and it works well for him, then other farmers will quickly follow suit, this will then be discussed within the group. **Demonstration farms** and focus farmers have a key role in this process. Participatory budgeting could be a strategy to foster cooperation among farmers. For the implementation of multi-farmer participatory approaches, the presence of a valid innovation broker (often a team of trained experts), is crucial. Innovation in NCWM has significant policy relevance, however in most European countries, **innovation brokerage** (i.e. extension service), has been delegated by governments to the private sector. There is a need to restore the link between public policies and on-farm practices. More effort should be put into building **infrastructures** that bring together farmers, advisers and researchers to foster knowledge creation and exchange, adaptive co-learning, and the adoption of innovation. The future CAP gives Member States more opportunities to strengthen the role of AKIS (Agricultural Knowledge and Innovation Systems) to link public policies and on-farm practices.
- ▶ **Multi-stakeholder action research** should be promoted, which takes into account the multidimensional nature of the NCWM problem (environmental, social and economic dimensions of sustainability), the effect at geographical and time scale of stakeholders' decisions and the different and often contrasting interests and objectives of various stakeholders involved.

- ▶ Analyses of the **profitability of NCWM** vs chemical weed management at both micro-economic (farm level) and macro-economic (regional, national and European levels), are needed to give useful information to steer future actions in this field.
- ▶ Engagement of **young farmers (schools, university)**. In order to enable young farmers to practice NCWM, this should be integrated into both the practice and theory of their courses, at an early stage. Young people are often more flexible and open to new ideas.
- ▶ The current process of specialisation of farmers, explained by the greater ease of acquiring technical control, the amortisation of agricultural equipment and the organisation of work with some crops in which the farmer specialises. For instance, long rotations with permanent crops, like pastures, requires local animal husbandry or industry (feed mills or pellets for alfalfa; dairy infrastructures). **Regional infrastructures to support changes in cropping systems**, such as new crops and products are needed.

Dissemination of information

- ▶ The point of view of **farmers' associations** have great influence on agriculture. They have an important role in dissemination of information and knowledge on NCWM. Trade journals are often published by the farmers' associations and they are an essential source of information. Headlines strongly influence the course of action. They are an important medium for disseminating information regarding NCWM. Other methods could include the Mayor's office, rural fairs and shows.
- ▶ Information can also be disseminated through mobile phones and **social media**, which has the advantage of being quick, flexible, accessible and user-friendly. In this case, information can be spread not only fast but also widely. It is important to use these media as a source of **positive information** on farmers and NCWM.

Annex A. Members of the Focus Group

Name of the expert	Profession	Country
<u>Marzia RANALDO</u>	Scientist	Italy
<u>Ilse Ankjær Rasmussen</u>	Farmers Organisation	Denmark
<u>Alistair Murdoch</u>	Scientist	United Kingdom
Dirk Jan Beuling	Farmer	The Netherlands
<u>Isabel Calha</u>	Scientist	Portugal
<u>Nicola Cannon</u>	Scientist	United Kingdom
<u>Demosthenis Chachalis</u>	Scientist	Greece
<u>Lieven Delanote</u>	Scientist	Belgium
<u>Hans Ulrich Dierauer</u>	Scientist	Germany

<u>Stefan Kuebler</u>	Expert from industry	Germany
<u>François Henriët</u>	Farm adviser	Belgium
<u>Jesenko Toncka</u>	Farm adviser	Slovenia
<u>Bo Melander</u>	Scientist	Denmark
<u>Jose Montull</u>	Farm adviser	Spain
<u>Bertrand Omon</u>	Scientist	France
<u>Alain Rodriguez</u>	Farm adviser	France
<u>Per Stahl</u>	Farm adviser	Sweden
<u>Judith Treis</u>	Farm adviser/Farmer	Germany
<u>Ben Colchester</u>	Farmer	United Kingdom

Facilitation team

Marleen Riemens	Coordinating expert
Remco Schreuder	Task manager
Emilie Gätje	Back-up task manager

You can contact Focus Group members through the online **EIP-AGRI Network**. Only registered users can access this area. If you already have an account, [you can log in here](#). If you want to become part of the **EIP-AGRI Network**, [please register to the website through this link](#)

Annex B. List of mini-papers

All mini-papers can be downloaded from the '[Non-chemical weed management' Focus Group page](#) on the EIP-AGRI website.

	Title	Main author	Other authors
1	A vision for the opportunities for precision non-chemical weed management in 2050 and beyond	Nicola Cannon	Bo Melander, Per Ståhl, Stefan Kuebler , Alistair Murdoch, Margaret R. McCollough, Dirk Jan Beuling
2	Farmers perceptions and decision making	Marzia Ranaldo	Ben Colchester, Judith Treis, Manuela Rosian
3	Breeding for weed-suppressive and tolerant varieties/crops	Ilse A. Rasmussen	Hansueli Dierauer, Marleen Riemens
4	Adapt practices according to weed biology	Alain Rodriguez	Lieven DeLanote, Francois Henriët
5	Cropping System Design For Non-Chemical Weed Management	Isabel Calha	Demosthenis Chacalis, Jose Montull, Bertrand Omon, Toncka Jesenko



The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

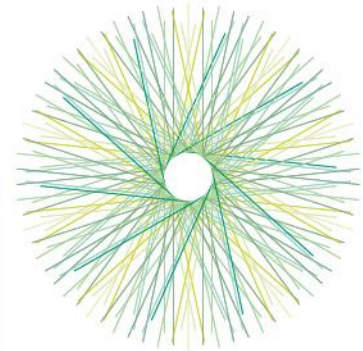
- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

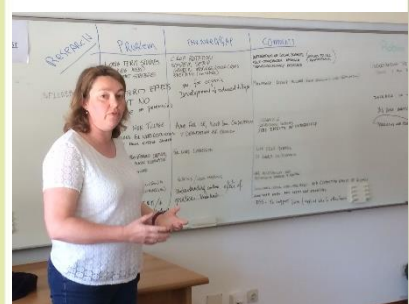
Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:

http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf



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