Weed control in new production contexts

Technical solutions and feedback on experience for sustainable management

Summary of the 2015 meeting of the GIS GC HP2E and the RMT Florad

Laurent BASILICO

A meeting on sustainable weed management in arable crops was held by the GIS GC HP2E and the RMT Florad, on December 15th 2015, in Paris. This summary is available on the websites of the GIS and the RMT.

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Foreword

Key elements of field crop productivity — the nature and methods of weed control — are undergoing major changes. Weed management strategies still depend heavily on herbicide use, but farmers have been confronted with new production contexts over the last 15 years, due to changes in regulations and in the expectations of society. There is a need to decrease the dependence of cropping systems on chemical inputs. But how can this be achieved? And how can we best preserve biodiversity and water quality without any loss of agronomic or economic performances?

No-till cropping techniques are becoming increasingly widespread in France, and this has led to evaluations of methods for compensating for the loss of the cleansing effect of ploughing. The judicious use of cover crops, the implementation of particular sowing techniques and innovative cropping systems are potential solutions for sustainable weed management. The key issue, for all those involved in field crop production, is to identify the practical combinations most likely to yield the best results in particular pedoclimatic contexts and the constraints placed on each farm. The GIS GC-HP2E and the RMT Florad organised a national meeting to facilitate the dissemination of information and debate on these issues, which took place in Paris, on December 15th 2015. This meeting brought together more than a hundred participants, including researchers, agricultural extension workers, public authorities and farmers. A set of cropping trials and scientific results were presented and the participants provided feedback on their experiences. This document provides a summary of the knowledge presented at this meeting and of the reflections it generated.

INRA : N. Beaucardet

THE GIS GC HP2E


INRA : Y. Bouchery

Following the *Grenelle de l'environnement* (an open multi-party debate on environmental issues that took place in 2007 in France), INRA and several technical institutes from field crop sectors (Arvalis, Terres Inovia, the ITB), APCA and Onema formed a group of scientific interest (GIS) aiming to develop innovative cropping systems for field crops with high economic and environmental performances.

They were joined by GEVES, GNIS, FNAMS, DGER-MAAP, AgroParisTech, Coop de France, Vivescia, ACTA, ITAB, FNA, InVivo Agrosolutions, Terrena, Axéréal, UIPP, FNE, Irstea, Syngenta, Bayer SAS and UNIFA.

This GIS was designed to function as a co-operative for the planning and organisation of R&D projects focusing on the following topics: plant breeding, sustainable weed management, sustainable soil management and analyses of the performances of field crop systems.

www.gchp2e.fr

THE MULTIDISCIPLINARY TECHNOLOGICAL NETWORK OF WEED MANAGEMENT (*RESEAU MIXTE TECHNOLOGIQUE*, RMT FLORAD)

Increasing awareness of the environmental consequences (water pollution, loss of biodiversity) of herbicide use have made it necessary to rethink the ways in which we manage the weed flora. Innovation is essential in the design and development of new practices and new mixed technical procedures combining knowledge in agronomy and ecology with mechanical and chemical weeding. The RMT Florad was set up in 2007 and extended in 2011. It brings together public research organisations (INRA UMR Agroecology, AgroSup Dijon), institutes and technical centres (ACTA, ARVALIS Institut du Végétal, Terres Inovia, IFV, ITAB, ITB), chambers of agriculture (CA33), agricultural training institutions (EPLEFPA Toulouse Auzeville, EPLEFPA Bordeaux Gironde, AgroSup Dijon) and co-operatives (IN VIVO).

This RMT is run jointly by ACTA (Alain Rodriguez), INRA UMR Agroecology (Sabrina Gaba) and the Gironde Chamber of Agriculture (Pascal Guilbault). Its general aims are: (i) to explore new fields of action and to develop R&D projects to identify and rank the most important topics, to obtain clear and useful responses to the questions posed; (ii) to provide expertise and to strengthen links with national and regional working groups and to disseminate the results obtained through training, technology transfer and the communication of information. The results of this approach are available from the organisation's website: www.florad.org

INRA : G. Louviot

SUMMARY

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"La vie est hérissée de ces épines, et je n'y sais d'autre remède que de cultiver son jardin."
(Life is full of these thorns, and I know of no other remedy than to cultivate your garden)
Voltaire

Introduction

Any mention of crops inevitably involves mention of soil…and when we talk about soil, it's impossible to avoid the subject of weeds. These plants, which compete with the crop for resources, are a continual concern for gardeners and cereal farmers alike. Their management is essential to the economic and environmental performances of farms. In the middle of the 20th century, developed countries moved towards production systems based largely on the use of effective, simple-to-use chemical herbicides. But things are now changing. Public awareness of the impact of phytosanitary products on human health and the environment has increased, in the context of a generalised decrease in biodiversity. Decreasing the pollution of soils and water with chemical contaminants, particularly those of agricultural origin, has become a major demand of society, and this demand has been enshrined in sweeping changes to the regulations in force. At European level, the water framework directive (WFD) of 2000 has driven unprecedented efforts to achieve a "good" chemical and ecological status for all bodies of water. This objective also led, in 2009, to a new directive controlling the use of pesticides and banning or restricting the use of the molecules of greatest concern.

In France, following the *Grenelle de l'environnement*, these changes led to the implementation in 2009 of the Ecophyto Plan, which aimed to decrease the use of pesticides by 50% by 2018. Herbicides account for 40% of the pesticides used in France. This plan led to a number of incentives and constraints being imposed. Particular efforts were made to protect catchment areas for drinking water, including heavy restrictions on the use of chemical inputs.

In parallel, the systematic use of tillage was called into question, and simplified cultivation techniques, which often require less energy and are less damaging to the soil, were being developed. These changes presented farmers with new challenges in weed control, in terms of the development of perennial weeds and the composition of the weed flora. In these contexts, various alternative solutions emerged for achieving weed control with a lower level of dependence on herbicides: sowing techniques, changes in sowing date, the use of cover crops and the diversification of

rotations. The use of solutions based on the valorisation of weed biodiversity and the services it provides (pollination, biological control) has also been encouraged, as part of the global action plan for agroecology of the Ministry of Agriculture ("*Produisons autrement*", "Let's produce differently"). Given the diverse package of alternatives possible, stakeholders in field crop production are waiting for concrete information about the combinations of practices providing the best compromise between weed control, economic and environmental performance and respect for regulations, taking into account the specific constraints on each farm. A large number of trials have been carried out on experimental or commercial farms in France, with a view to providing answers to these questions. The results of some of these studies were presented and discussed at a meeting organised by the GIS GC-HP2E and the RMT Florad, to prime a new dynamic of exchange and practice sharing at the national level. The following pages provide a short summary of the contributions made at this meeting and the questions raised, in four sections dealing with the various solutions for disturbing the weed flora, the combinations of practices likely to optimise control, the means of implementing these measures and assisting farmers and, finally, the likely directions to be taken by R&D in the future.

The complete proceedings of the meeting can be obtained from:
www.gchp2e.fr and www.florad.org

APAD

Sowing techniques, innovative cropping systems and cover crops:
concrete experiences

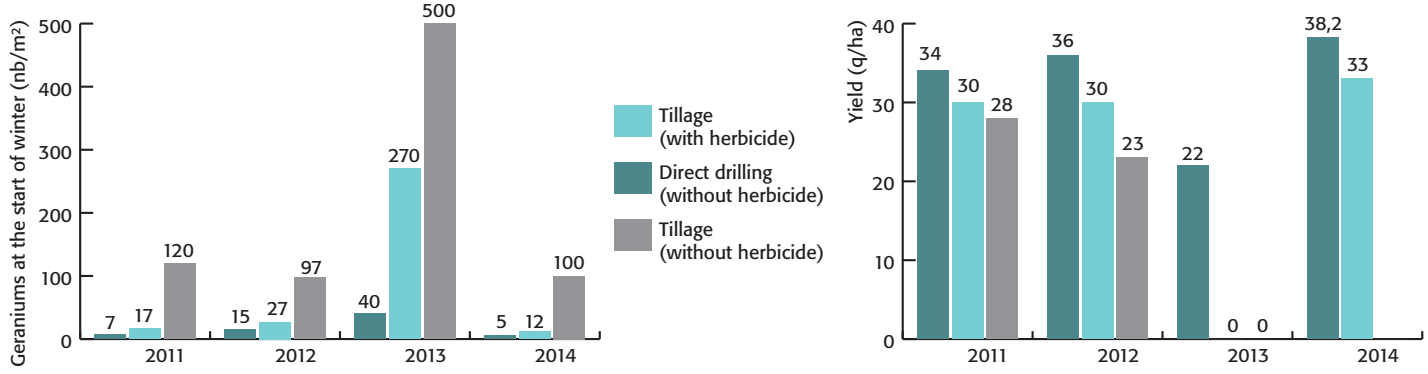
1

A decrease in herbicide dependence, in a context of minimal soil tillage and increasing use of cover crops, could potentially modify the seed bank. Solutions in all areas of weed management, from sowing techniques to changes in the cropping system, will thus be required to modify weed development. This first section describes some of the results obtained in different contexts, which will serve as useful guides for those involved in field crop production, on a case-by-case basis, when trying to modify their cropping strategies.

Sowing techniques and intercropping: conclusive trials for oilseed rape

Terres Inovia, in their studies at experimental stations or on commercial farms, have quantified the efficacy of several of these solutions in the context of a short oilseed rape/wheat/barley rotation, on the superficial clayey calcareous soils of the Centre and Lorraine regions of France, much of which is now managed with minimum tillage practices and subject to strong weed pressure (e.g. geraniums, cleavers, blackgrass, ryegrass). Some of these trials aimed to improve the growth dynamics of oilseed rape through innovative sowing practices. **Direct drilling**, with a disc seed drill operating at low speed (less than 7 km/h), **was found to be highly effective in this particular situation** (weed invasion, lack of effective herbicides, weed bank consisting largely of species displaying little or no dormancy). This approach made it possible to decrease geranium seedling levels by 85 to 95%, versus only 46 to 88% for herbicides on a tilled soil (see figure 1). In addition, **the combination of direct drilling with the intercropping of certain frost-sensitive leguminous species** was found to limit weed development. The combination of these techniques in an innovative technical schedule (direct drilling of the crop together with a frost-sensitive legume, little or no broadleaf weed herbicide applied, 30% decrease in fertiliser applications) between 2011 and 2014 secured yields, even leading in some cases to significant gains with respect to the classic technical schedule including soil tillage and treatment with a full dose of herbicide. Weed cover was lower in oilseed rape intercropped with a frost-sensitive legume than in oilseed rape grown alone, and this effect was particularly marked if the wet weight of the total biomass (oilseed rape + cover crop) at the start of winter exceeded 1.5 kg/m², a situation rarely observed with oilseed rape grown alone.

Figure 1 : Results for geranium and oilseed rape yield, for tillage and direct drilling
(Source : Terres Inovia)



Another way of outcompeting weeds would be the use of **intercropping**. For example, trials monitored by the ESA of Angers at nine sites in West France demonstrated a beneficial effect of growing winter lupin with triticale: lupin yields were little affected (as shown by comparison with the sole crop), whereas the biomass of weeds at flowering and at maturity was much lower when lupin was grown with triticale (63% and 56% lower, respectively).

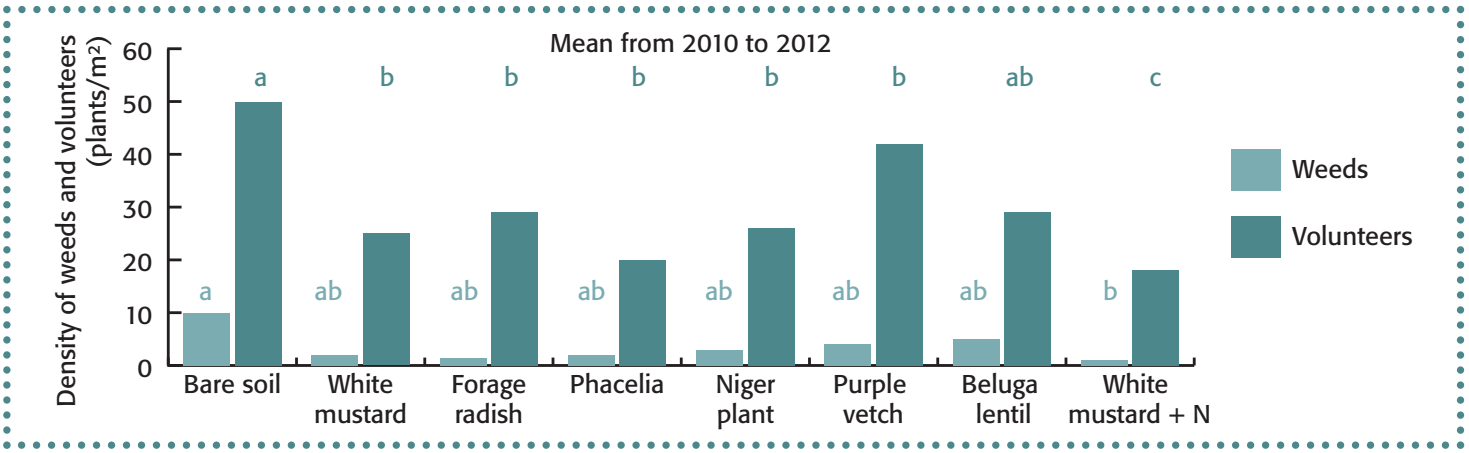
Changes in cropping systems: no turnkey solution

In the longer term, the objective of modifying weed populations in a durable manner to decrease the amounts of herbicide applied will require changes in cropping systems. In the same context of clayey calcareous soils, Terra Inovia compared the reference rotation, oilseed rape/wheat/barley, with a winter pea + barley cover crop/oilseed rape/wheat/barley/sunflower/wheat rotation. The results were mixed. Yields and yield margins were maintained, and the goal of decreasing nitrogen fertiliser levels by 30% was achieved. However, phytosanitary product use decreased by only 25% (versus the 50% anticipated), and there was even a slight increase in the treatment frequency index (TFI) for total herbicides. The succession of pea and oilseed rape in the rotation increased the risk of weed infestation in this context. This observation highlights the lack of turnkey solutions in terms of cropping systems, which must **be adapted to the pedo-climatic and production contexts**. Long-term experimentation in the framework of the SYPPRE inter-institute project will provide additional elements for the radical redesign of cropping systems, through experimentation over a period of 20 years with diversification of species and sowing dates and the succession of two spring crops in the rotation.

Cover crops during the inter-crop period: effective against volunteers, but less so against weeds in general

Cover crops are increasingly used between two main crops in France, both for agronomic reasons and to ensure compliance with regulations (the nitrates directive). Arvalis carried out two long-term trials at Boigneville (Paris Basin) to investigate the impact of cover crops on weeds and crop volunteers. The first of these trials, carried out from 2003 to 2013, compared the effects on weeds and crop volunteers, both between crops and in the next crop, of various species or mixtures of cover crop species sown in mid-August, by comparison with a control soil maintained bare through chemical weed control treatments. The second trial, set up in 1992, investigated the effects of ground cover on the weed flora and crop volunteers between crops and during the cropping season, for different types of soil tillage and different plant cover destruction methods. The results differed between years, but the presence of ground cover generally led to a clear **decrease in crop volunteers during the period between crops**, regardless of the species grown (figure 2).

Figure 2 : Mean effect of different types of plant cover on the density of weeds and crop volunteers between crops *(Source : Arvalis-Institut du végétal)*



By contrast, although most of the cover plants used decreased the density of weeds with respect to that observed on bare soil (with the exception of a large number of *Senecio* plants in the second trial, in direct drilling conditions), this effect was significant only for white mustard with fertiliser application. The density of weeds between crops also appeared to be higher in direct drilling conditions than with soil tillage. In general, the biomass of the cover crop was found to have a large effect on the limitation of weed development and crop volunteers. It has also been found that **cover crops have no effect on weed infestation in the following crop**, despite the lower capacity for intervention between crops to prevent seed set.

Plant cover appears to be effective for controlling crop volunteers. However, its effects on the weed flora are much less clear and should be evaluated and compared with those of traditional agronomic practices (use of a false seed bed, seed bank depletion). Finally, in some cases, the **introduction of a temporary grassland** may be a relevant option for the qualitative and quantitative regulation of the weed flora. Trials at the SOERE-ACBB experimental centre at Lusignan have confirmed the efficacy of this approach and made it possible to identify the mechanisms at work — direct competition with the grassland cover or, in the longer term, changes in the weed seed bank. However, the results suggest that the grassland must be maintained for a period of at least three years to observe changes in the weed seed bank.

INRA : H. Meiss

2 Which combinations of practices optimise weed control?

The efficacy of weed management strategies depends on complex interactions between many determinants: sowing techniques and dates, the varieties used, associated crops and the crop rotation, for example. On their own, each of these various alternative approaches, like those described in the preceding section, often have only a limited effect. In the quest for sustainable weed control, farmers need to know which combinations of practices are the most effective. This section describes several presentations from the meeting that dealt with this issue.

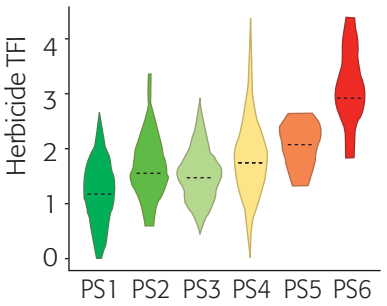
With simplified tillage, more herbicides but less inputs of other types

The "winning" combinations are, of course, dependent on the pedoclimatic and historical contexts of the farm, which vary considerably in France. An analysis of existing databases can help to outline the key characteristics of typical contexts. The working group of the GIS GC-HP2E on sustainable soil management studied the effects on weed management of decreasing soil tillage. It made use of the results of a survey (Agreste, 2011) of 20,827 plots assigned to 52 groups on the basis of their agropedoclimatic context. The statistical analysis confirmed that the differences in weed management between tillage and no-tillage techniques concerned principally herbicide use, with levels of herbicide use generally higher in direct drilling conditions. By contrast, lower levels of other phytosanitary products (fungicides, insecticides) were used in the absence of tillage.

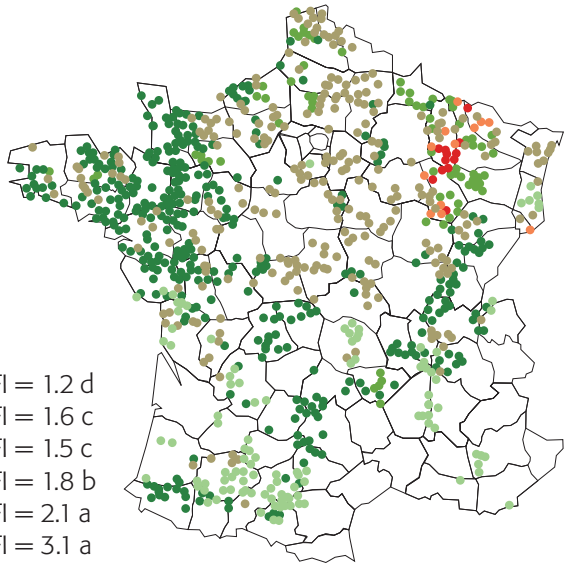
Each production context has its own optimal agronomic strategies

A similar approach was applied (InVivo Agrosolutions-INRA) to monitoring data for the DEPHY-Ecophyto farm network, corresponding to 1000 different cropping systems. These cropping systems were classified in terms of major production situations (PS) according to pedoclimatic context and the presence or absence of livestock farming. For each PS, a typology of the agronomic strategies used was established (figure 3).

Figure 3 : Distribution of herbicide consumption according to PS in the DEPHY-Ecophyto farm network



Explanatory variables
- Soil type
- Climatic variables
- Socio-economic context, association with livestock farming, industrial crops



6 types of context

PS1: with livestock production, West and South,	mean TFI = 1.2 d
PS2: with livestock production, North and North-East,	mean TFI = 1.6 c
PS3: without livestock production, South and Southern Alsace,	mean TFI = 1.5 c
PS4: without livestock production, Centre and North,	mean TFI = 1.8 b
PS5: without livestock production, North East, acidic-to-neutral soil,	mean TFI = 2.1 a
PS6: without livestock production, North East, basic soils,	mean TFI = 3.1 a

A statistical analysis was carried out to identify the combinations of practices resulting in the lowest levels of herbicide use according to the treatment frequency index (TFI) at the cropping system scale (six production situations, see figure 3), for crops of winter wheat (five types) and maize (two types). For each system, it was possible to identify the strategy resulting in the lowest level of herbicide use. These strategies generally included **more diverse crop rotations** in terms of the species introduced and the sowing period (for example, alternation of winter and spring crops), and tillage, at the cropping system scale. Mechanical or localised weeding and the use of a false seed bed were considered to be more occasional means of weed control.

At Epieds, tillage and a lengthening of the rotation decreased weed density by a factor of eight

A larger number of *in situ* studies will be required to refine the analysis for a given type of situation. This was the motivation behind a trial carried out by Arvalis between 2006 and 2014 on a superficial stony silt soil at Epieds (Normandy region). This experiment aimed to compare the effects of different types of soil tillage and different sowing dates on the weed flora, for three rotations: wheat monoculture, oilseed rape/wheat/wheat and oilseed rape/wheat/spring protein crop/wheat. Inventories of the weed flora were obtained for each plot, with a zone not treated with herbicide used as the reference. This approach delivered quantitative comparisons between the different approaches, in terms of weed management, distribution of working time, fuel consumption and margins.

It was found, in particular, that the combination of tillage and a longer rotation decreased weed density by a factor of eight relative to the reference conditions (oilseed rape/wheat/wheat and no tillage). The addition of a third measure, the use of a later sowing date, had little effect in this case. In general, **the effect of tillage is more important in systems including few other measures**. However, the combination of agronomic measures systematically favoured weed control. Delayed sowing decreased weed density by a factor of three on plots without tillage, and the effect of lengthening the rotation was also more marked in such conditions.

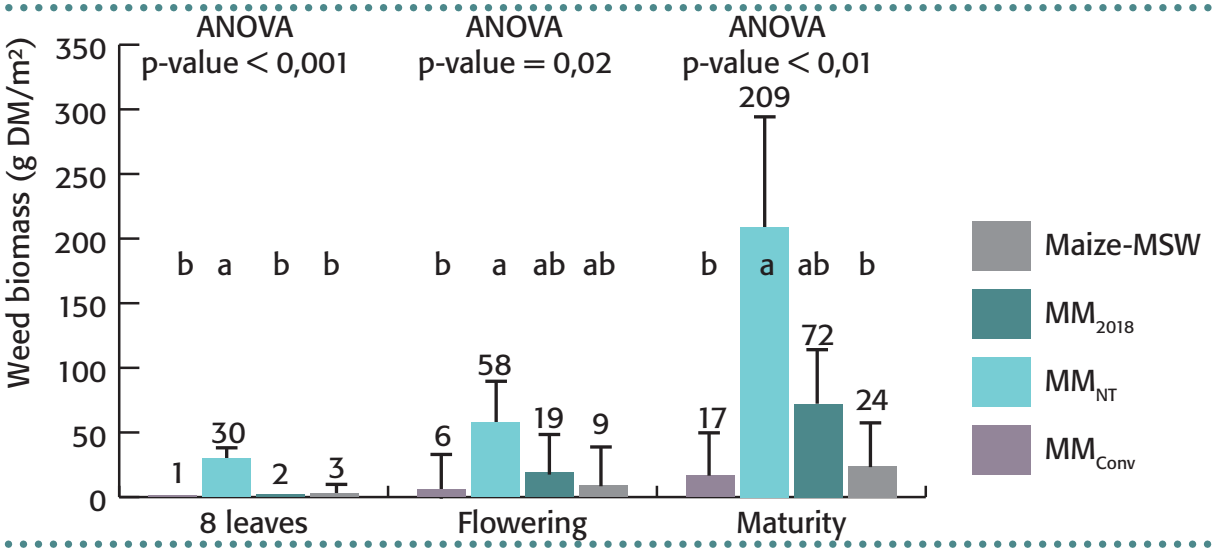
Maize in a "southern" context: four technical schedules under the microscope

Another study carried out since 2011 by the *École d'ingénieurs de Purpan*, focuses on maize monocultures in the South-West of France, in which herbicides account for 78% of the total TFI. *In situ* experiments comparing weed densities and yields are carried out in four different cropping systems, to identify ways of decreasing this herbicide dependence:

- MM_{conv} "conventional" (annual tillage, chemical weeding, bare soil between crops, late variety);
- MM_{2018} "low inputs" (annual tillage, mixed or mechanical weeding, ryegrass and clover cover between crops, semi-early variety);
- MM_{NT} "no tillage", aiming to decrease working time by 50% and to reduce energy consumption and the leaching of inputs (chemical weeding, cover between crops, semi-early variety);
- A maize/soybean/soft wheat rotation (MSW) aiming to limit peaks of work, TFI, irrigation and leaching.

Each year, infestation is assessed at about the 6-8 leaf stage of the maize crop, at flowering and at maturity.

Figure 4 : Comparison of the changes in weed biomass between the four technical schedules for a maize crop *(Source : Ecole d'ingénieurs de Purpan)*



The results for weed biomass (figure 4), yield and TFI led to several conclusions. Unsurprisingly, the "conventional" system was the most stable, combining a high yield (11.3 t/ha) with effective weed management. **The low-input system was the alternative system giving the best compromise** between yield (10.6 t/ha) and decrease in TFI (68% lower than for the conventional system). The maize/soybean/wheat system (9.7 t/ha for maize) was the most efficient for weed management. Finally, the no tillage system (8.2 t/ha), which was marked by an explosion of the grass population at maturity, highlighted the difficulties of systems of this type for maize monoculture.

Finally, the work presented in this section confirms that it should be possible, in all production systems, to find agronomic strategies making it possible to decrease herbicide usage, through the combination of several different measures. Other initiatives will contribute to this approach, as in the framework of the "zero pesticides" (Rés0Pest) experimental network. However, it remains a challenge to reconcile statistical approaches, which identify general directions in particular contexts or types of context, and *in situ* trials, which deliver information that is more precise but limited to given situations. The wider use of such approaches, together with modelling (see section 4), should make it possible to move forward, **from local references to transposable principles** usable by farmers confronted with their own specific constraints and the reality of their farms.

INRA : G. Louviot

How can these approaches be used by farmers and what help should be provided?

3

In parallel to technical solutions, as described in the previous sections, the other major challenge is determining how these elements can be used by farmers in the context of their own farms, whether to overcome an impasse or to move towards other ways of controlling weeds. For these entrepreneurs, operating in highly competitive markets, changing the system is a long process (several years) that is not risk-free in terms of productivity and, thus, revenue. This third chapter, based on feedback on real experiences, deals with several reflections and questions raised during the meeting, concerning the help that farmers need to change their practices.

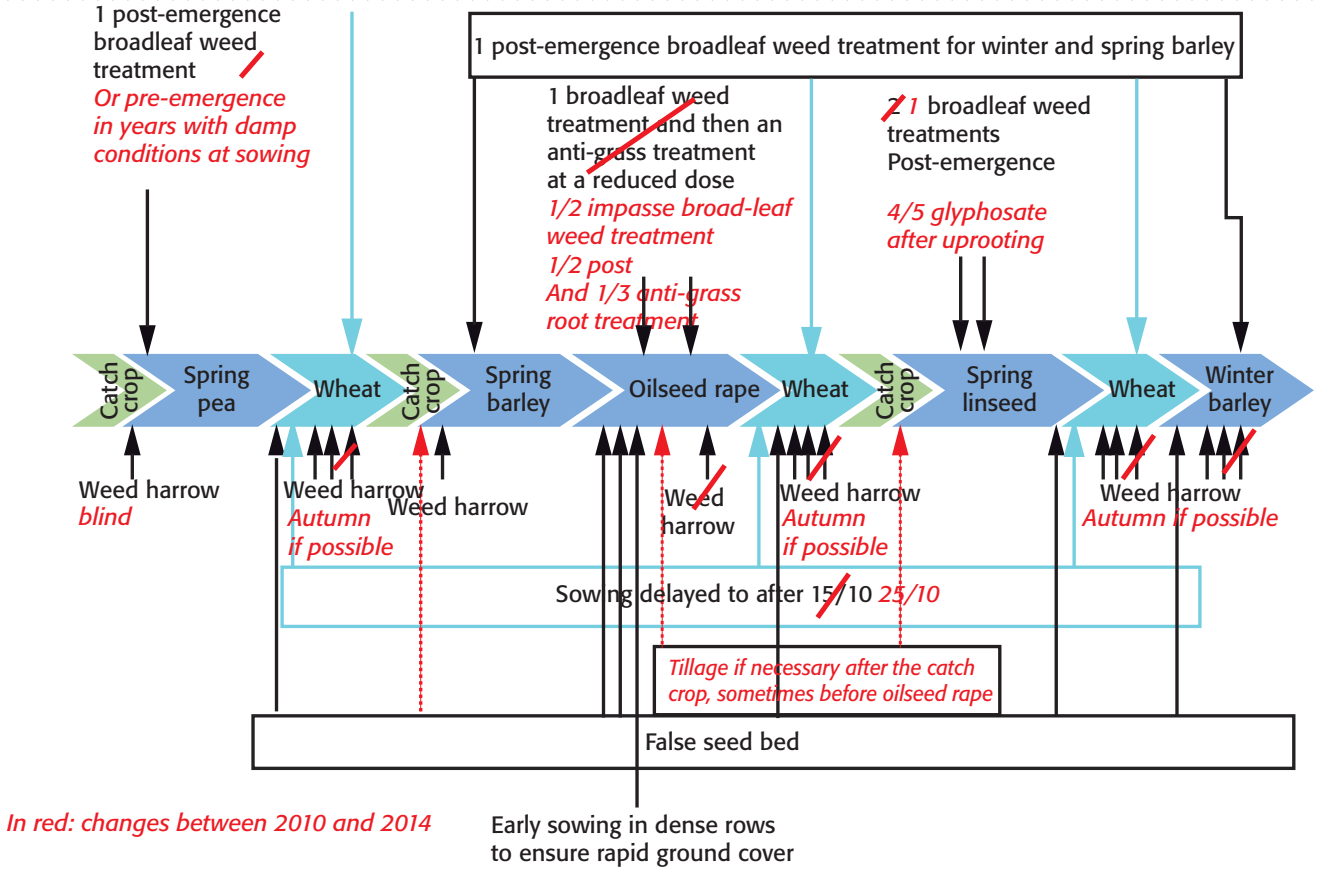
Benefiting from the experience of others: networking is essential

During the transition towards a new cropping system, a group of farmers working together is one of the most powerful factors favouring success. This co-operation favours the acquisition of new methods and concepts and allows farmers to benefit from their neighbours' experiences when making decisions for their own farms. This necessary emulation is today supported by various networks, such as the DEPHY Fermes network, the cornerstone of the Ecophyto Plan, or co-operative structures such as APADs (*associations pour une agriculture durable*; sustainable agriculture associations). The DEPHY 27 group described its experiences during the meeting. This group contains about a dozen farmers developing very diverse cropping systems, including beet, hemp and maize in particular, with everything from frequent tillage to no tillage at all. However, at the outset, all the members of this group had the same goal: weed control with a single full dose of herbicide per year.

Season after season, this objective was supported by a **common methodology** based around cropping system concepts and a decision flow-chart for weed management. This formalisation made it possible to structure exchanges concerning the combination of measures with partial effects, establishing a dynamic process of joint cropping system design. This facilitated controlled changes in the cropping systems, several major types of which were identified within the group: systems with temporary grasslands and relatively frequent tillage (robust with a sober use of chemical inputs) to systems with little diversity and little or no tillage — the most strained. For each type of system, **adjustments were designed collectively** and implemented between 2010 and 2014 (see figure 5 - p. 14).

INRA : A-H Cain

Figure 5 : Synopsis of the changes made to a type of cropping system in the DEPHY 27 group
(Source : CA27)



After the introduction of these changes, weed control was considered generally satisfactory, with **TFI values well below the regional reference values**, with the exception of a few systems. Finally, in a more qualitative manner, working together encouraged these farmers to **put things into perspective with respect to the "norms" of the job** and their own perception of plots containing weeds as "dirty". It enabled them to rethink their cropping systems, with a more flexible, adaptable and resilient design.

Individual initiatives to be encouraged…

Independently of any incentives or existing solutions, the leading driver of change is the strategies of the farmers themselves, their aspirations and their notion of the job. An example of voluntary change was given during the meeting by Philippe Mouraux, a cereal farmer from Lorraine belonging to the local APAD. Beginning with a situation of impasse with simplified cropping techniques, with blackgrass and brome grass contamination, he described his ten years of transition to a direct drilling system with a cover crop. He described the non-linear nature of this transition: a difficult start, the emergence of unexpected problems (and new weeds) and their empirical resolution, in an **approach involving continual adjustment**. The current system has restored productivity and led to the sustainable management of weeds, although the overall TFI has decreased only slightly. He combines seed protection with insecticide, surface treatment with lime, cover crops with five or six locally present species, straw crushing and other diverse agroecological measures to combat voles (hedges and nesting boxes for owls).

...and technical and financial assistance to be developed

This successful experience, like many others, was the result of individual motivation and collective maturation, in this case within the APAD network. The establishment of targeted means of assistance would appear to be essential, to favour developments of this type. The provision of documents and decision support tools (the ECOHERBI guide developed by the RMT Florad, Infloweb, R-sim, Odera…) should be long-term and should involve a **strengthening of support networks and structures**, which have already been shown to favour the appropriation of solutions. These networks should be equipped with standardised tools making it possible to compare the results obtained in different places, as in the protocols for observing weed pressure developed in the framework of the Casimir project for the DEPHY networks.

A move towards the larger scale management of weeds, with the restoration of **closer links between farms growing field crops and livestock farms** would also appear to be desirable. A diversification of co-operative members could contribute to this movement. GIEEs (*groupements d'intérêt économique et environnemental*; groups of economic and environmental interest) bringing together all the stakeholders concerned by a particular subject within a given area, would be another relevant link in the chain supporting this development. They could provide institutions with assistance.

Finally, economic assistance is also required. Data concerning **analysis of the risks associated with changes in cropping system** are eagerly awaited. They would make it possible to objectify the process and to determine the amount of funding required to deal with these risks in a similar manner to the existing systems for the transition to organic agriculture.

INRA : C. Maitre

4 The next step: what direction for future R&D?

The last part of the meeting was dedicated to the identification of new measures for extending the possibilities for integrated weed management and to the questions that these approaches, which are often radically different from current ideas, pose for research. This session yielded a fertile debate fuelled by cross-sectional expertise and the presentation of recent results, many based on the concept of "agroecology", during the final roundtable.

Five major courses of action for weed control and avenues to be explored for each

A vital issue for the future of field crops, the search for new responses to the problem of weeds, has led, both in research and in the field, to many studies, new avenues to be explored and new ideas. Xavier Reboud (INRA Dijon) proposed an ordered panorama of these different approaches by listing them in an original conceptual framework with five major pathways for managing the weed flora as its point of entry. This typology (see table 1) provides a relevant analysis grid for assessing the 17 measures identified as potentially usable to support the Ecophyto II initiative.

Table 1: Distribution between five weed-management pathways of 17 potential measures to support the Ecophyto II initiative

A – Occupying niches to ensure that no space is left vacant
- Sowing of cover crops to limit weed germination
- Use of varieties providing a high degree of ground cover
- Cropping practices leading to the selection of weeds with a lesser impact

B – Preventing the development of plants after their germination
- Mechanical weeding
- Use of false seedbeds for the germination of seeds in a superficial horizon
- Greater bioavailability of pesticides
- Development of bioherbicides
- Use of herbicides specifically to manage weed infestations between crops

C – Exhausting the weed seed bank and preventing its renewal
- Actions against the reservoir of dormant seeds in the soil
- Introduction of lucerne or another pluriannual cover crop into grassland
- Straw recovery or crushing
- Cutting
- Encouraging the damping off of weed species

D – Presenting an unusual situation to which the species to avoid cannot adapt
- Diversification of rotations with respect to weeds and other bioaggressors
- Introduction of practices that break up monotony (mulches, solarisation phases, crops with allelopathic effects etc.)

E – Optimising practices: explicit coupling of the detection of a species with targeted action
- Precision agriculture (drones, cameras) to increase weeding efficiency
- Weeding robots; still at the prototype stage

Prioritising R&D efforts: the "biological principles mobilised" approach

In this framework, the potential efficacy of a measure for integrated weed management can be evaluated by the "biological principles mobilised approach". In this approach, it is postulated that **the effect of introducing a new measure will be greater and more durable if it influences several different management pathways**.

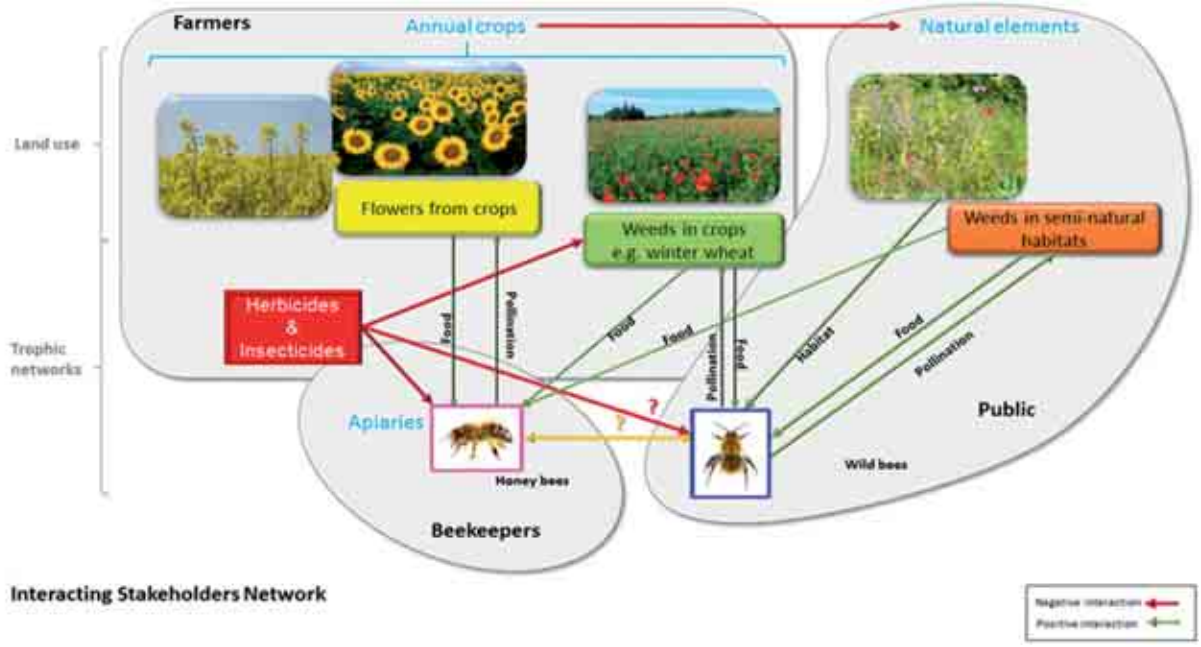
For example, the introduction of a cover crop is a pathway B measure (preventing the development of plants after their germination) but it also affects pathways A, C and D, suggesting that it is potentially a very influential measure. On the contrary, **the management of weed seeds during harvesting**, which has been put forward as a very promising measure by several authors (Walsh, Newman & Powles, 2013), mobilises essentially only one weed management pathway, pathway C. This may lead to **a risk of the weed flora overcoming this measure** with time. This analysis grid could be improved, but it is highly pertinent for rational assessments of the likely durability of the various measures envisaged. Other criteria should also be considered, such as the compromise between feasibility and efficacy, or the degree to which measures can be adapted to existing systems.

Agroecology and ecosystem services: an alternative approach to developing low-input systems

In addition to technological measures, another approach based on the principles of agroecology could constitute a major element of tomorrow's solutions. This alternative approach is based on the valorisation of biodiversity, including weeds, by postulating that the **ecosystem services** provided (biological control, pollination) can compensate for a decrease in the use of chemical inputs, such as pesticides. Recent results fuelled the debate on this issue at the meeting. In particular, the role of weeds in the maintenance of agrosystem biodiversity, often seen as a constraint in the design of cropping systems, was proposed as a possible measure for meeting the objectives of the Ecophyto Plan (S. Gaba, INRA Dijon).

This notion, put forward in the ANR AGROBIOSE project, paves the way for innovative reflections on the notion of **weed biodiversity**, including, in particular, the associated pollination services (figure 6) for sustainable management of the flora at the scale of an agricultural territory. However, this inevitably raises the question of the effect of weeds on agricultural production. INRA Dijon and the CNRS at Chizé carried out **an empirical analysis** to analyse the relationships between herbicide use and the abundance and

Figure 6: Unexpected role of weeds in agricultural oilseed rape and sunflower crops through complex interactions between weeds, crops and domesticated and wild bees.
Source : Bretagnolle & Gaba (2015), Agronomy for Sustainable Development

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richness of the flora and agricultural production on 150 plots worked by 30 farmers in the Plaine & Val de Sèvre workshop zone in 2013 and 2014 (ZA-PVS ; http://www.za.plainevalsevre.cnrs.fr/). This analysis identified difficulties in obtaining a clear correlation between the intensity of herbicide use and the abundance or richness of the weed flora. Further studies of the effects of weeds on agricultural production and of the effect of herbicides for controlling the flora are therefore required, including long-term experiments taking seed bank dynamics into account.

More generally, the agroecological approach is opening up a vast field of research into weed management. Other contributions to the meeting provided innovative elements improving our understanding of the effects on the weed flora of the **presence of trees in field crops** (agroforestry) or of **weed seed predation by ground beetles**. The identification of effective combinations of such measures and their integration into systems with a high economic performance will undoubtedly be one of the great challenges of R&D in agronomy in the future.

Resistances, modelling: more topical than ever

In addition to these quite prospective approaches, the roundtable participants highlighted the importance of pursuing R&D efforts to improve and maintain the efficacy of current methods of weed management. **Herbicide resistance** phenomena were raised little in the plenary sessions but were a recurrent theme during the discussions. They remain, of course, a key challenge in agrochemical research. The objective is, more than ever, to optimise the efficacy of the doses applied and to implement strategies to prevent these phenomena (by decreasing selection pressure, in particular). In this context, the availability of tests for resistance would make it possible to avoid applying treatments that have become ineffective locally.

Other major research themes were highlighted during the meeting. Over the next 10 years, major advances are anticipated in the domain of **precision agriculture**, with self-driving hoes guided by cameras and GPS and making use of imaging to localize and identify weeds. The emergence of these tools should also lead to further R&D, to optimize their potential and their integration into production systems.

In parallel, **modelling approaches** will provide precious support for predicting the effects of the combinations of measures available, today and tomorrow, for management of the weed flora in the context of various types of farm. This is the aim of the ANR CoSAC (*Conception de Stratégies durables de gestion des Adventices dans un contexte de Changement*; Design of sustainable weed management strategies in a context of change) project, designed and set up by the GIS GC-HP2E, launched in 2015 and coordinated by INRA.

Finally, improvements in our **knowledge of the biology of weed species** remain particularly necessary in integrated approaches. We need to know the specific features of a weed if we are to disturb its lifecycle effectively. The use of cover crops or intercropping raises a paradox and paves the way for reflections on the use of non-competitive species for ground cover. The weed flora is an inertial system, due to the presence of the seed bank, but it is also plastic and sensitive to changes in practices. Its management thus requires a dynamic approach and evaluations of changes in practices take a long time.

Conclusion

The richness and diversity of the contributions presented during this 2015 meeting bear witness to the dynamic established by public authorities, research, technical centres and stakeholders from the domain of field crop production for the design of sustainable strategies for weed management. In an era of simplified cropping techniques and the Ecophyto plan, the principal technical options currently available for decreasing the dependence of systems on herbicides have now been identified. Many agronomic trials, often carried out on commercial farms, have provided new information about the efficacy of these measures for given crops, exploitation histories and pedoclimatic contexts. These studies are increasingly aiming to determine the effects of combinations of measures ; they better take into account the evolution of cropping systems in the long term and the inertial effects associated with the seed stock. A collection of avenues for research and development has been identified, to enlarge the range of options available in the future, notably through greater use of precision agriculture techniques and the principles of agroecology, from biological control to agroforestry.

However, every plot is different, and much remains to be done to improve the transfer of these findings to the only people capable of translating them into action in the field, farmers. With this objective in mind, the first major axis of research remains the exploitation of local reference data (for a weed flora, soil type or cropping system) to construct operational principles transposable to other conditions. In addition to pursuing current trials and performing additional trials in diverse contexts, the success of this approach will require modelling and statistical analysis to characterise the sensitivity of these measures to different production systems, to facilitate decision support.

The second major challenge remains the implementation of change by farmers, and the assistance that this will require, adapted to the strategic plans of the farmer for his or her farm. The integration of this diversity of exploitation strategies will be a challenge for agricultural R&D. Feedback on experience and exchanges during the meeting identified a few important components. The integration of farmers into peer working groups, at the scale of an agricultural territory, seems to be a key factor for success. This working together leads to the development of common tools and methods, the gradual adjustment of technical strategies and allows the farmers to take stock of their own practices and habits in a way that they would not normally do. These observations confirm the need to maintain and strengthen the existing support networks and structures in the

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long term, as in the DEPHY networks. In parallel with this technical support, it will be necessary to create or develop risk analysis tools to consolidate changes in the system in economic terms. This analysis will make it possible to create specific assistance measures for supporting changes in systems or practices or reinforcing those that already exist (the Plants for Environment Plan, facilitating the acquisition of mechanical weeding equipment or equipment for limiting the drifting of herbicides during spraying, *Mesures agro-environnementales et climatiques* ; Agro-environmental and climate measures relating to water or biodiversity, conversion to organic agriculture etc.).

The key issue tackled by the Ecophyto II Plan, that of the management of weeds in field crops, has long been a preoccupation in French agriculture and is increasingly taking on a multi-stakeholder dimension. The growing mobilisation of the various actors and the development of a calm national debate during the 2015 meeting of the GIS GC-HP2E and the RMT Florad marked a key moment in the history of this issue. Such mobilisation and debate will need to be pursued in the coming years and will help to open up the issue of weeds, favouring a more integrated reasoning of changes to systems at the crossroads of food, water and air quality and the conservation of biodiversity.

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