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Full report

Glyphosate use and alternatives in French agriculture

Avoiding glyphosate, taming the heterogeneities

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Glyphosate use and alternatives in French agriculture

Executive summary

This report follows a request to INRA from the Ministries of Agriculture and Food, Ecological Transition and Solidarity, Health, and Higher Education and Research for an analysis of glyphosate use, the identification of possible alternatives alongside their economic and organisational implications, and suggestions for supporting measures to facilitate the transition to glyphosate-free production systems.

The short time-span given for the response to this request led to an analysis based on readily available data (farms in the DEPHY Ecophyto network, national and international reports, scientific and technical publications) and a consultation with experts from INRA, CIRAD, IRSTEA, France's Agricultural Technical Institutes, Chambers of Agriculture and professional agricultural organisations.

With all uses combined, more than 9,100 tonnes of active ingredient was used in mainland France in 2016 (BNVD data from the national databank of distributors' sales). Glyphosate is used in agriculture to manage/destroy swards and meadows, to eliminate weeds in fields before sowing while avoiding tillage, and to control difficult weed flora (perennial, invasive, allergenic or toxic species). By blocking the chain of synthesis of essential amino acid precursors, glyphosate has the only herbicidal mode of action with the twin properties of being total (all plants share the blocked mechanism and therefore all are sensitive to varying degrees) and systemic (it migrates into tissues allowing it to reach root systems). This can destroy or contain plant cover crops and control weed species of particular concern. As a result of its widespread use, glyphosate and its metabolites are found in water and soil and, fortunately very rarely, in agricultural commodities. The request made to INRA does not concern the toxicological and ecotoxicological risks associated with the various uses of glyphosate.

1. **The analysis of the results of research and experimentation and the practices of farmers seeking to avoid glyphosate use has made it possible to identify various technical alternatives.**

Alternatives must make it possible to maintain pressure on weed populations, to ensure the destruction of plant cover before crops are sown, to manage vines and orchards, and to facilitate harvesting in controlled situations. If glyphosate is removed from the equation then farmers, seeking to maintain their income and yield levels, will need to employ the following alternatives, either alone or in combination:

- Physical destruction through mechanical weeding and surface tillage, especially during the intercrop period for annual crops, or around the base of vines and trees in the case of viticulture and arboriculture.
- Ploughing to ensure the destruction by burial of all vegetation. This also buries weed seeds that are on the surface, preventing their emergence during the following season, but limits their predation by insects.
- The sum of partial avoidance strategies, including the use of winter freezing of intermediate cover crops through the choice of adapted species, or the use of specific agricultural equipment for grinding vegetation. This avoids the need for total chemical destruction.
- Cropping under living mulches, which induces a profound change in weed flora and a limitation of perennial or problematic weeds.
- The targeted use of other listed herbicides (which may have more adverse toxicological and ecotoxicological profiles than glyphosate) may be required during a transition period to treat perennial weeds that have withstood the previous options.

An analysis of practices based on data from the 3,000 farms in the DEPHY Ecophyto network shows that farmers are already using these levers. They are therefore possible and even economically viable when they are considered with a view to coupling interventions to limit extra costs, and when reflecting at the cropping system scale. The major obstacles identified concern the economic impact and working time, changes in the equipment required, motorisation and automation, and planting methods for perennial crops. The consideration of a transition to the avoidance of glyphosate use must therefore be conducted at a time scale that takes into account the implementation of these alternative techniques.

2. **With the support of the Chambers of Agriculture and Agricultural Technical Institutes, we have identified difficult situations and impasses regarding these levers and the current knowledge available.**

We consider that there is an impasse when the only feasible alternative in the short term is to destroy the perennial flora by hand. Impassess concern:

• The special case of conservation agriculture, currently covering about 4% of the cultivated area. There is no effective alternative to glyphosate to maintain a field over the long term without tilling the soil. This type of agriculture, which restores the soil and stores carbon, was built because glyphosate made possible the twin actions of destroying intercrop covers (nitrate directive) and managing the perennial flora. These farmers could be led to abandon their principles and reintroduce superficial tillage, sometimes even ploughing.

• Agriculture conducted in difficult conditions without the benefit of high added value: terraces, very stony areas and very fragile areas with regard to erosion risk. This category includes situations encountered in France's overseas departments and vineyards or orchards on steep slopes. The surface area concerned is not precisely known.

• Crops for specific markets with strong technical constraints. The seed production sector (380,000 ha including 70,700 ha dedicated to the most difficult forage, vegetable and floral species to manage) as well as fresh and canned vegetables grown in open fields (203,560 ha in 2014, of which 61% was on arable farms) with the risk of the presence of fragments from toxic weeds, fall into this category,

• Niche situations such as the retting of flax fibre (88,000 ha in 2016), of which France is the world's leading producer, and the harvesting of nuts (19,000 ha in 2014).

Farm monitoring suggests that, in a rationale of redesigning which is at work to reduce the use of plant protection products in field crops, arboriculture and vines, as in the French overseas departments, there may be changes in management methods where interventions that would have taken place anyway are newly positioned to cover the role of what glyphosate was doing. Meeting a set of economic, social and environmental and biodiversity objectives is a technical challenge, so the speed of transition envisaged must take into account difficulties and impasses. As a result, the pace of farmers' adaptation will be affected both by the crops concerned, their technicality and the equipment available, but also specific soil and climate conditions.

3. **Assessing extra economic costs is difficult**

For the diversity of the productions concerned, economic impacts will depend largely on their effects on other techniques, changes in the rotation if profitability is no longer guaranteed, labour costs that vary from situation to situation according to the local labour availability, and, on the same farm, according to pedoclimatic conditions. Between production and farm, the economic impact will be all the more marked if crop diversification is low, livestock is not involved and the sector concerned is affected by highly competitive markets within the European Union.

4. **Adaptation to a halt in glyphosate use involves and will continue to involve profound changes.**

The deployment of new practices should be considered on all farms, regardless of size, especially large ones. Efficiency, workflows and technical skills will be the three keys to success.

This can and should guide the choices of farmers, professional organisations and research towards:

- A generalised ability to characterise and manage intra-plot heterogeneity in order to better target chemical or mechanical intervention where it is essential. Mapping perennial flora in the fields meets this expectation.
- An enhanced ability to take into account environmental conditions conducive to chemical or mechanical interventions to ensure their effectiveness; the crop development stage and the bearing capacity of the ground must be continuously available, and these two points should guide the innovations to be led by the sector exploring advances in precision agriculture.
- Increased automation (backed by adapted regulations), especially in vegetable production.
- The development of a wider range of inter-crop species and cover crops built around the criterion of ease of management (quality of establishment, ease of mechanical destruction); this point may require reviewing regulations on intermediate crops around the use of irrigation for crop establishment and a small dose of fertiliser.
- Increased use of hoed cropping, including in a generalised way for certain arable crops which currently do not use it; varieties adapted to this cropping mode will be necessary.
- A broadening of the range of mechanical weeding tools for better efficiency at lower cost, and a change in the regulations to facilitate its use during the intercrop period.
- Implementation of management methods to gradually reduce weed reserves in the soil, whether they are in the form of seed banks or vegetative organs.
- Innovative chemical or alternative control methods specifically targeting certain species of public health concern or major obstacles to current virtuous practices even in organic farming: ragweed, thistles, Rumex species, bindweed, quackgrass, Datura species, nightshade, and the devitalisation of sugar cane rhizomes.

5. **Many of these changes are compatible with a reduction in herbicide dependence beyond glyphosate alone.**

For more than 20 years, research and applied research have conducted work to minimise pesticide use and even to dispense with it. Innovative cropping systems, demonstrating technical feasibility in long-term programmes, have been carried out. Many of these have targeted pesticides other than glyphosate which are considered to be of greater concern, including insecticides that damage beneficial entomofauna. Mechanical weeding is a logical choice, but these approaches have underlined the importance of thinking at the system scale before implementation. This will also be the case in arboriculture, for example, where raised irrigation will have to be chosen as it is the only method compatible with the passage of mowing or tillage tools at the foot of trees. This research underlines the importance of prophylactic measures to limit weed pressure. The revision and redesign of different cropping systems is necessary because of the many interactions between practices.

The main bottlenecks may be of a biotechnical nature or result from France’s agricultural trajectory that has led to (i) large farms with little use of labour, (ii) territorial specialisation which limits alternative land uses and favours the selection of problematic weed flora, (iii) market standards and specifications. The analysis of transitions must also integrate these structural dimensions. The transition to the absence of glyphosate will also be facilitated by an adaptation of consumer demand and the harmonisation of practices among European countries to limit competitive distortions.

6. Recommended supporting measures for the removal of glyphosate

These include investment aid, the use of MAEC systems (France's agro-environmental and climate measures), the mobilisation of the collective dynamics in agriculture, agricultural advisory services and training, the use of regulations and in particular CEPP (France's pesticide savings certificates) and the organisation of value chains, notably by promoting the recognition of products from glyphosate-free sectors.

Research and applied research will also play a role in improving the efficiency and ease of implementation of available alternative techniques and in creating new options, whether they are new levers through biological control or methods for the control of intra-plot heterogeneity.

1- Introduction

1-1 Short reminder of the request

On November 2 2017, four ministries (Ecological Transition and Solidarity, Health, Agriculture and Food, and Higher Education, Research and Innovation) jointly asked INRA to conduct a study before a possible national plan to end glyphosate use, announced by the Prime Minister and set to be defined by the end of 2017. The text of the request can be found in Appendix A of this report.

This request was made in the context of a reassessment of glyphosate approval at the European level. At the time of writing, discussions were under way about the European Commission's proposal for a renewal of its approval for five years, renewable or not depending on the interpretation of Member States. This position is considered insufficient by the French authorities, especially in view of the remaining uncertainties about the impact of this active ingredient on human health, with many publications addressing this including the most recently published on November 9 (Andreotti *et al*., 2018), animal health and, more broadly, the environment.

This report does not deal with the links to public health or the environment, which would justify or not a ban on glyphosate in the longer or shorter term. According to the terms of the request, it instead focuses solely on the main current uses of glyphosate in France, on the identifiable alternatives for each of these uses, and the economic and organisational implications of their deployment and on the support which could aid their implementation. Likewise, this report does not deal with the withdrawal of pesticides, although it may respect the spirit, as it focuses on the issue of glyphosate. We will try, to the extent of the data available, to show how the withdrawal of glyphosate is in keeping with an overall reduction in pesticide use in general and herbicides in particular.

Taking into account the quantities and areas concerned and the data available, the study will rely heavily on quantitative data for only arable crops and viticulture in mainland France. This has been supplemented by an expert analysis of the situation in France's overseas departments and sheds light on arboriculture, where the similarities between France and Germany have been explored.

1-2 Context

In 2017, glyphosate was the most widely used herbicide in the world. It is a systemic herbicide that has the property of circulating in the plant and reaching those parts of the plant under the soil. It is also a herbicide described as 'total' to illustrate its broad spectrum of action against almost all plant species. It inhibits the enzyme EPSP synthase (enolpyruvylshikimate-3-phosphate synthase) which catalyzes the condensation of shikimate-3-phosphate and phosphoenolpyruvate to 5-enolpyruvylshikimate-3-phosphate. Glyphosate binds to the active site of phosphoenolpyruvate and exerts competitive inhibition. EPSP synthase is the penultimate stage of the shikimic acid pathway, which produces chorismate and leads to aromatic amino acids: phenylalanine, tyrosine and tryptophan (INRA Collective Scientific Expertise on Herbicide Tolerant Varieties, 2011). Glyphosate is registered for use in agriculture as well as in gardens, infrastructure and green spaces. This report focuses on agricultural use in France, for which 8,400 tonnes were marketed in 2016 (data from France's national databank of distributors' sales). The uses observed in France are largely the same as those found in other countries of the world with some notable exceptions, such as its use as a pre-harvest crop desiccant, which is no longer practised in France, and its use for weeding during the season (post-emergence) on glyphosate-tolerant GMO varieties of various major crops which are not grown on French soil.

For each use of glyphosate, the study looked for existing or future alternatives and characterised them in order to indicate to the public authorities the environmental and economic implications of changes in practices and possible support measures. There is no single answer to the question of the economic impact of a ban on glyphosate because different cropping systems do not face the same dependence on its use and the solutions which would allow glyphosate to be dispensed with vary according to the system. To put forward a number would be rather risky and premature in the context of this study.

We have decided to focus on the choices made at the farm scale in order to be able to highlight coherent existing or potential crop management plans that could be implemented in the absence of glyphosate. Some current systems have become glyphosate-dependent as the result of a technological lock-in for a molecule which is inexpensive and offers recognised efficacy (such as the positioning of irrigation in orchards which prevents the passage of tillage tools). The organisational changes which could provide the services currently rendered by glyphosate are supported by real-life situations. Despite the recommendations of the request not to focus on chemical substitution solutions involving another active ingredient, we have found it essential to recall that from a practical point of view this replacement will be required in some management plans.

The report relies as much as possible on glyphosate alternatives which can already be found on farms and are therefore mature solutions that have proven their feasibility. Research and development has looked at other more innovative avenues, testing their suitability and efficacy, which we present here too. Like other organisations, INRA has deployed a large part of its efforts and mobilised its experimental systems to develop and evaluate cropping systems less dependent on synthetic pesticides, but without focusing specifically on glyphosate. These experiments generate references to frame the possible implications of the large-scale deployment of agricultural systems without pesticides in general and glyphosate in particular.

1-3 Outline of the approach taken

Given the time available and the absence of exhaustive data, the study conducted was **not** conducted according to the principles of the institutional scientific expertise charter[1] to which INRA committed itself in 2011.

The study carried out here relies first and foremost on the individual expertise of a small number of INRA experts, selected for their excellent agronomic skills, the extent of their scientific and concrete knowledge about cropping practices and systems in France and their ability to grasp the systemic dimension of the questions asked. They have combined their own knowledge with that of a large number of technical experts who were interviewed and conducted a comparative analysis of real-life cases when the databases available made this possible. The latter sought to contrast systems using glyphosate and those not using it in order to highlight the alternatives to the use of this herbicide and its consequences. The selection bias that such an approach can generate was here controlled thanks to the agronomic and systemic skills of the experts involved.

Given the deadlines set and the nature of the request, this study does not rely directly on a systematic exploration and in-depth analysis of the existing scientific literature on the subject. This knowledge and critical perspective concerning scientific results is assumed to be acquired through the skills of the experts involved, with the biases and knowledge gaps that such an approach can include. Furthermore, despite the breadth of view of the experts involved, their disciplinary origins in agronomy can limit the depth of the analyses presented here. This means that the absence of economists (except in France's overseas territories) and social scientists leads to a partial coverage of these important dimensions,

[1] Collective document (2011). Charte INRA de l'Expertise Scientifique Institutionnelle. Delegation for Collective Scientific Expertise, Foresight and Advanced Studies (DEPE), February 2011. http://inra.dam.front.pad.brainsonic.com/ressources/afile/234000-94d50-resource-expertise-charte-inra.html

limited to only a reflection on the potential additional costs of alternatives (especially in equipment) and not being able to go beyond an analysis of changes in short-term gross margins.

In the time allotted for the study, we used the complete series from 2008 to 2016 of France's national database of distributors' sales (BNV-D) and directly approached the country's agricultural statistics service (SSP) for its surveys on agricultural practices using the exploitable data from the latest season available. Finally, we used data from Ecophyto's DEPHY farm network from the date at which arable farms and vineyards entered the system (called 'point zero') allowing us to produce a quantitative analysis of practices. In addition to this information, a qualitative analysis of farm trajectories which included a reduction in herbicide use, particularly glyphosate, in their objectives helps to shed light on possible transitions.

The study reported here was lead by INRA, with the support of the national organisation units of the DEPHY network and SSP, and included consultation sessions with IRSTEA, ACTA's agricultural technical institutes, CIRAD and RITA. In particular, we organised two sessions dedicated to exchanges with these partners on November 15 and 20 2017, which allowed us to benefit from their expertise and to discuss expert knowledge on alternatives to glyphosate. During these sessions, engineers and members of the CGEDD-IGAS-CGAAER group (an inter-ministerial project studying the implementation of a gradual withdrawal of pesticides) also contributed. Finally, members of the independent evaluation committee of CEPP (France's pesticide savings certificates) also contributed to this work.

2 - Methodology used

Because of the short time given to complete this study, we have conducted quantitative studies on the basis of readily available data (national statistical data from SSP and data from the DEPHY farm network for arable crops and viticulture in mainland France), and drawn on the knowledge of experts in these sectors and of expertise in France's overseas tropical sectors.

We have focused our study on agricultural use, as usage in gardens, green spaces and infrastructure (known in French by the initials JEVI) is subject to specific regulatory texts limiting glyphosate use to issues of public safety and preservation of national heritage (Law No. 2014-110 of February 6, 2014, as amended by Law No. 2015-992 of August 17 2015 on Energy Transition for Green Growth and by Law No. 2017-348 of March 20 2017 on combating the monopolisation of agricultural land and the development of biocontrol).

2-1 Datasets available

Three main sources make it possible to document glyphosate use in France and its evolution:

The national databank of distributors' sales (BNV-D). This base is fed by distributors' declarations of annual sales of phytopharmaceutical products transmitted to France's agencies and water boards. It is of both a regulatory and official nature since the implementation of France's water law means these declarations are part of the fee for diffuse pollution. Wider access has recently been granted to this database (http://www.data.eaufrance.fr/jdd/660d6c71-6ae3-4d51-be4d-faf73567643e) and it has been clearly defined (https://bnvd.ineris.fr/). As its name suggests, it compiles annually the sales volumes of phytopharmaceutical products expressed in quantities of active ingredients. It does have well-known limits, though, which take two forms.

First, the registry summarises in a single annualised value the overall sales volume of each active ingredient, without tracking its projected uses. If in the vast majority of cases an active ingredient has one particular use and is used at a relatively homogeneous dose depending on this use, the value provided can be easily connected to the equivalent surface area treated and the crops concerned. This is not the case when the phytopharmaceutical active ingredient has a broad spectrum and homologous doses vary depending on its use (from arable crops to flowering crops and for uses outside the strict agricultural field, for example, exceptional situations in JEVI). In the case of glyphosate, the dose varies by a factor of 2 to 5 depending on its use on young annual weeds and established perennials. The interpretation of glyphosate use on the basis of the quantities sold is therefore tricky.

The second limit relates to the difference between place of sale and place of application (Groshens, 2014). However, without being able to document it, it is reasonable to think that use will primarily occur in the county of sale or neighbouring counties.

Surveys of cropping practices conducted by the Ministry of Agriculture's statistics and foresight department (SSP/Agreste PK survey). These surveys are now an integral part of the follow-up to the Ecophyto Action Plan which aims to gradually reduce the use of plant protection products. In addition, they provide France's response to regulation (EC) 1185/2009 of the European Parliament and Council of 25 November 2009 on pesticide statistics. The survey does not cover all major crop categories each year. It aims to reconstruct in outline, all or part of the technical management of the crop under study. In particular, it serves to check the commitment to particular specifications: previous crops, soil preparation, sowing, fertilisation, pest control, irrigation, yields and the rationale for interventions[2]. The latest surveys for which statistics are available are 2011 for arable crops (with a partial supplement in 2014), 2013 for vegetables and viticulture and 2015 for arboriculture. The exploitation of these geolocalised data requires compliance with the regulations on individual data, which is strictly controlled by SSP via a data access control system that has not facilitated their 'urgent' exploitation in this study. These data are valuable because of the large numbers surveyed and the representativeness of the sample. In this study, they have been used to quantify glyphosate use and to explore the alternative practices of farmers who do not use it.

The SSP arable crop datasets cover 19,661 conventional fields in 2011 and 19,282 fields in 2014. The selected crops are soft wheat, durum wheat, winter barley, spring barley, triticale, oilseed rape, sunflower, winter pea, spring pea, silage maize, grain maize, beet and potato. In each situation, the survey can reveal not only the precise technical itinerary for the crop being surveyed, but also the cropping history and the use of ploughing (or not) over the five previous cropping seasons. Also, the information makes it possible to quantify glyphosate use during the intercrop period (preceding the crop being surveyed) and to cross it, among others, with the types and number of tillage interventions. This database is regularly updated (approximately every four years) by field surveys of agricultural practices and crop management at the spatial scale of the field and at the time scale of the crop cycle. The viticulture data used in this report concerns the latest validated datasets for viticultural technical itineraries in 2006 (5,216 plots) and 2010 (6,264 plots), supplemented by those of Mailly *et al*., (2017).

The DEPHY farm network was created as part of Ecophyto. When each farm entered the network, it accurately described all its technical itineraries over the previous three years (2009, 2010 and 2011 for the oldest farms). This 'point zero' data from the DEPHY farms corresponds to 996 conventional arable cropping systems (i.e. 5,521 crop management technical itineraries), 1,049 conventional vineyards and 131 conventional orchards. In addition, the decision-making patterns of farmers are also indicated. These data are recorded in the Agrosyst database, managed by INRA.

The DEPHY network was built on a voluntary basis, with no attempt to be representative of French agriculture. For arable crops, a study has shown a fairly good correspondence between the DEPHY

[2] For example, see the summary on plant protection product use in vegetable crops http://agreste.agriculture.gouv.fr/IMG/pdf/dossier27_integral.pdf

network and national statistical data for many macro-indicators (soil type, rotation, pesticide use etc., see Lechenet, 2017). However, the voluntary nature of DEPHY farmers can generate a potential bias in practices. Consistent with their desire to make changes and reduce pesticide use, some farmers may tolerate more weeds in their fields, accept a slightly higher degree of risk or employ a few more technical levers as an alternative to herbicide use. In any case, the 'point zero' data correspond to DEPHY farmers' practices before any modification of the system envisaged in the DEPHY project. These practices are therefore likely to be close to the average national practices for arable crops in the period under review.

The period for which practices are registered (2009-2011) predates the widespread deployment of the nitrate directive, which since 2011 has led to changes in practices to generalise plant cover crops during intercropping periods, and specific management and destruction techniques for these cover crops.

These data describing the practices of DEPHY farms were used to (i) characterise glyphosate use, including in terms of its geographical structure, (ii) explain the variability of this use by highlighting the links with explanatory factors relating to the specificities of production contexts and farmers' agronomic strategies, and (iii) to evaluate the impacts of alternatives to glyphosate by comparing the economic and environmental performance of DEPHY cropping systems using glyphosate versus those not using glyphosate given equivalent production contexts and types of agronomic strategy.

We cannot conclude this section without recalling the crucial role played by the availability of complete datasets to objectify the different options. As such, there is good reason to welcome the Ecophyto approach for having radically changed the situation of the three sources that we could consult. Undoubtedly, there would be no comprehensive database of distributors' sales, the questionnaires on practices conducted by Agreste would not have been so detailed on the choice of crop protection and the use of upstream epidemiological surveillance information and, finally, we would not have real situations providing a snapshot and chronological trajectories without the network of DEPHY farms. The latter is undoubtedly the most striking point because it provides many elements demonstrating that other approaches to agriculture are possible and that the farmers who deploy them are often the first ambassadors for these approaches.

Our biggest problem in understanding some of the determinants mainly concerns the connection between the choice of crop management on the farm and the collection and processing channels in the choice of cash crops and crop successions. By way of illustration, competition from grass cover in an orchard can result in a change in the size of fruit, which does not necessarily have the same consequences if the crop is destined for processing or is aimed at fresh sales with its codified market standards. We also wondered about the possible consequences of pesticide bans on very small chains that do not usually have the critical mass to work on alternatives. They can also be highly localised so the state of the health of these chains can have strong positive or negative territorial repercussions. We also note large areas of uncertainty for illuminating the consequences of a withdrawal: i) the difficulty in clarifying the positive implications for health or biodiversity, ii) the relative difficulty in objectifying the possible margins for progress on alternative solutions once they have been put forward in terms of reliability, cost of use, workflows etc.; distinguishing what constitutes a genuine impasse is foresight or even speculative work, and we have avoided this.

2-2 Definition of tillage methods

For arable crops tillage is a major factor in the use of herbicides in general and glyphosate in particular, so it is essential to clearly define here the methods of use and tillage.

In arable crops, glyphosate is mainly used during the intercrop period, between the harvesting of one crop and the sowing of the next one. By convention, the treatment during this period is attributed to the technical itinerary of the following crop, in particular because this treatment contributes to the preparation of good sowing conditions for this crop.

There is a close functional link between the use of glyphosate and tillage, which requires a clear explanation of the vocabulary used. Ploughing is one form of tillage that is characterised by the inversion of the soil, with the most superficial horizons buried deep (at varying depths depending on the type of ploughing). A farmer can plough systematically every year, or more occasionally, or never. There are other forms of tillage which do not involve turning over the soil. These are often more superficial than ploughing and use tools with teeth or discs, or powered tools such as a rotary harrow. Some farmers practice no-till techniques, or simplified cultivation techniques (SCT) and only use these forms of tillage without turning the soil, often on large farms and often on land with low to intermediate potential, as this reduces working time for the preparation of seedbeds and sowing. Finally, some farmers, few in number but important for the 'glyphosate problem', do not work the soil at all. The only tillage is the action of a sowing disc digging a narrow furrow to accommodate the seeds sown, on a negligible proportion of the field's total surface. When this type of strategy is repeated systematically every year the strategy is classified as the 'direct sowing' type. In most cases, direct sowing is associated with the sowing of an intercrop cover to form a mulch of plant residues on the surface during intercropping which persists after the crop is sown to limit weed development. Direct sowing may be motivated by an even more drastic reduction of traction time in the field, but also driven by the desire to preserve soil quality (reducing erosion and improving biological quality) or environmental concerns (carbon storage and preservation of biodiversity).

2-3 Documentary resources consulted

We have endeavoured to consult various documentary resources beyond the scientific literature. We have also explored the international resources available.

Following requests through various channels, different groups in France have produced short summaries of uses, listing alternatives and highlighting difficulties. France's technical institutes and its academy of agriculture, in addition to NGOs, have produced documents that we consulted, and we sometimes had direct talks with the editors to clarify certain points. In particular, ACTA coordinated information from various experimental trials led by the technical institutes aimed precisely at testing technical itineraries without glyphosate use. Some issues of the journal TCS also shed light on the practices used to control cover crops during production under simplified cultivation techniques.

A study rather similar in its aims was conducted in Germany in 2015 under the coordination of the Julius Kühn Institute (Kehlenbeck *et al.*, 2015). Starting from the observation that there was a strong dependence on glyphosate, this study explored its main uses, quantifying the economic impact of the choice of one or more alternative solutions with particular emphasis on mechanical weeding. Finally, it listed the situations in which halting glyphosate use would seem to be the most problematic.

Studies carried out in Switzerland (the 'Oberacker' system, from INFORAMA Rütti to Zollikofen, Agroscope's P29C test in Changins) on the long-term evolution of a cropping system towards a reduction of tillage has made it possible to identify the mechanisms of glyphosate dependence.

Finally, a study conducted in Great Britain under the authority of the BBSRC clarified the work carried out to identify alternatives to synthetic pesticides and the consequences of changes in practices

(Global Food Security Workshop: Alternatives to conventional pesticides: understanding the efficacy and unintended consequences of a change in practice[3]).

3- Results

3-1 Distribution of volumes utilised between sectors; evolution over time

Having national usage data to present a snapshot or objectify a trend is not easy. Even sources that are seen as reliable and annually updated show evolutions which combine several antagonistic factors, making comparisons risky. As an illustration, the summary document produced for the sustainable development statistics for the period 2009-2015, drew attention to their particularity: "The BNV-D data do not provide information on the location of use but at the point of sale of the products by the distributors. Cross-border sales are not taken into account until 2012." (Datalab essentiel n ° 94 - March 2017).

The BNV-D database generally distinguishes between major sectors of use: agricultural or non-agricultural, professional or amateur, considered as a biocontrol product or for specific uses such as seed treatments. Between 2011 and 2016, glyphosate is found alone or mixed with other active ingredients in different categories of uses. Table 1 gives the sales of glyphosate between 2011 and 2016 translated into the equivalent quantity of active ingredient to take into account variations in composition from one formulation to another. The overall trend seems to be a relative stagnation in agricultural use coupled with a steady decline in non-agricultural use, in line with changes to the regulations.

Table 1: Overall sales of glyphosate (according to BNV-D)

Reporting year	Tonnage in quantity of active ingredient (QSA in French)	Share of non-agricultural use (%)
2011	**8,980**	**21.72**
2012	**9,730**	**20.92**
2013	**9,370**	**19.68**
2014	**10,070**	**18.52**
2015	**8,790**	**18.60**
2016	**9,110**	**16.14**

The major uses authorised in France cover contrasting situations over time, space and targets. So, the landscape of uses extends from the treatment of vines and orchards to the inter-row of some root crops, from the preparation of seedbeds to the management of intercrops, from combating perennial weeds to cleaning field edges. As the distribution of these situations is heterogeneous from one area to another, it makes sense to expect, without being able to guarantee that this is the only reason, that glyphosate use is heterogeneous at the scale of mainland France.

[3]https://www.foodsecurity.ac.uk/publications/alternatives-conventional-pesticides-understanding-efficacy-unintended-consequences-change-practice.pdf+&cd=1&hl=fr&ct=clnk&gl=fr

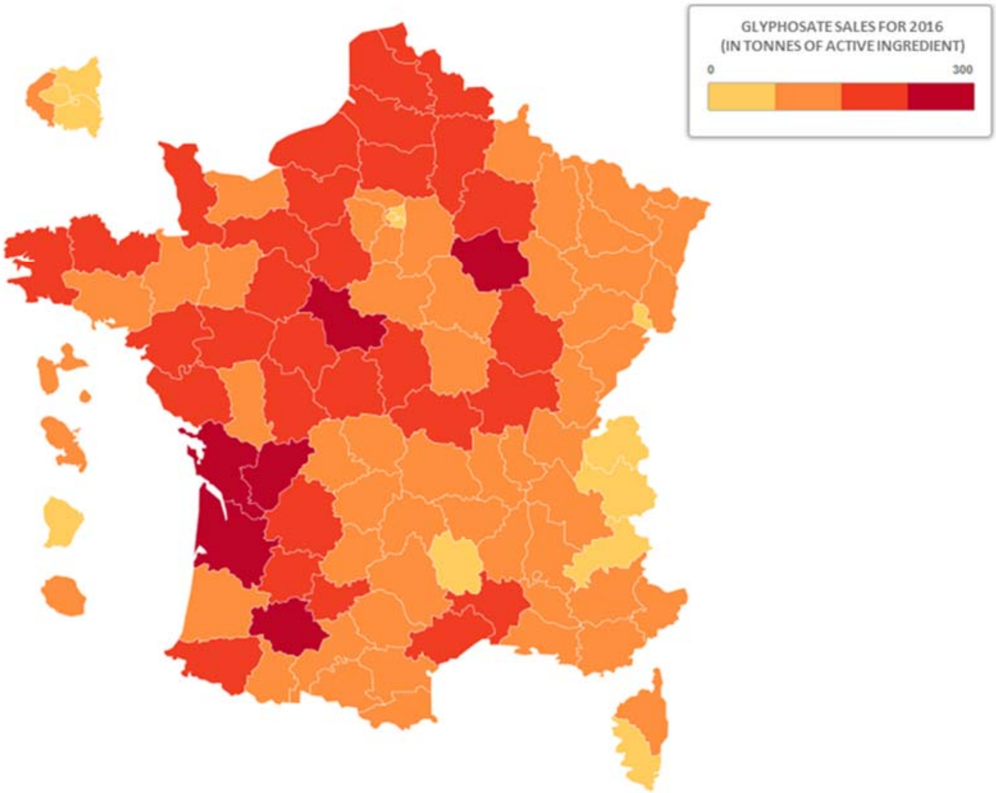


Figure 1: Map showing the distribution of glyphosate sales by department (equivalent of county). Data extracted from BNV-D. This is the map published on the francetvinfo website for the 2016 season. Key says: Glyphosate sales for 2016 (in tonnes of active ingredients).

On this map, it is as difficult to explain the contrast between Gironde and the Landes (in the south-west corner) just as it is to provide comment on the identical classification of Jura and Drome (south-east corn). It is similar when examining the scale of interannual variations. The map in Figure 2 compares glyphosate sales between 2012 and 2016. Within the data available in the BNV-D, these two years were chosen because 2016 offers the most recent data available and 2012 is the oldest year available in which the same calculation method was used. With regard to trends in the quantities of glyphosate used at the national scale, consumption ultimately varies very little. A comparison of sales volumes between two years generates a heterogeneous map, suggesting an underlying diversity in the origins of these variations (destruction of permanent grassland in the north, planting new orchards and vineyards in the south etc.).

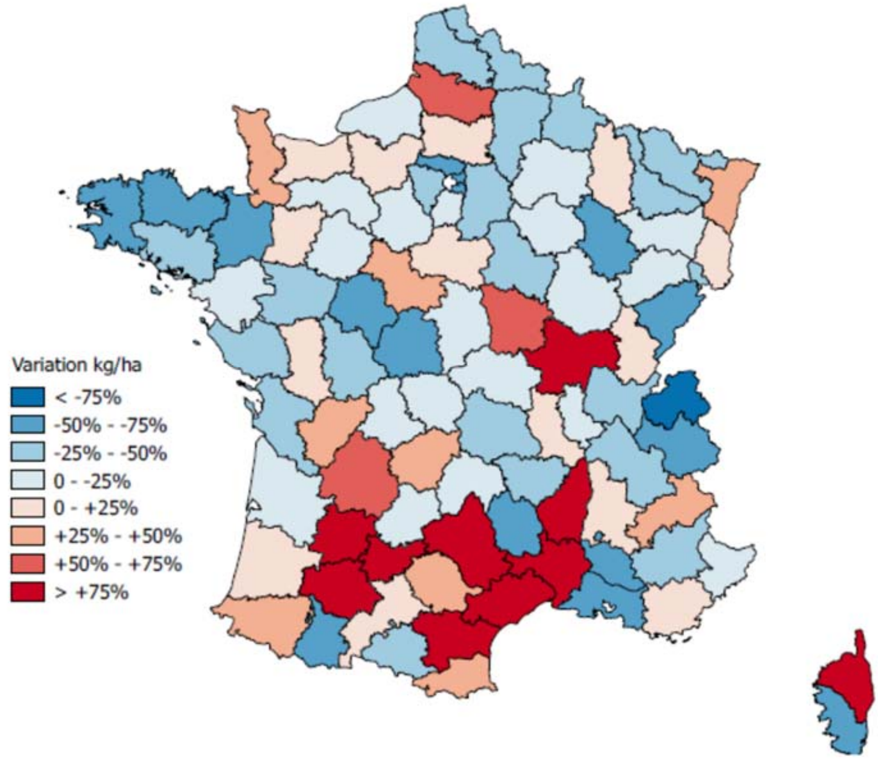


Figure 2: Map showing the variation in the quantity of glyphosate sold per hectare of UAA by department (equivalent of county) between 2012 and 2016.

These two maps illustrate the need to know the intended target and the crop concerned in order to clarify a general trend in glyphosate use nationally. Therefore, we will now develop these uses, trends and factors that may explain the geographic variation in glyphosate use from the DEPHY network's 'point zero' data, supplemented by data from Agreste agricultural statistics on practices, called SSP in the rest of this document.

3-2 Glyphosate use in arable crops in the DEPHY network and 2011 and 2014 SSP surveys

The analysis of farms in the DEPHY network, both those specialising in arable crops and mixed farms, reveals the following information:

- 57% of DEPHY cropping systems used glyphosate at least occasionally in the rotation when they entered the network. So, 43% of conventional DEPHY farmers never used it. There are several technical itineraries in a cropping system and an analysis of these shows that 28% of the technical itineraries included at least one glyphosate treatment.
- 95% of the treatments were performed 'in full' across the entire field. Very localised treatments, on field edges or weed 'hotspots' are therefore very minor.
- Pre-harvest treatments against perennials are very rare (0.1% of treatments). Some 4% of treatments are for the destruction of temporary grasslands (which are only chemically destroyed in 30% of cases). 26% of treatments corresponded to the destruction of intercropping cover and weeds which develop in them. The majority of the treatments (70%) were applied on soils without an intercrop but where regrowth had occurred and were used to destroy the weeds which developed during this period ahead of sowing. It is likely that this

proportion has decreased since the launch of the DEPHY network, with an increase in the area using intercrop cover crops due to the application of the nitrate directive in vulnerable areas.

- Approximately 10% of treatments are at perennial weed rates and 90% of treatments target annuals.

Glyphosate use as measured through the practices used varies with the duration of the intercrop and the sensitivity to competition during the germination and emergence phase of the chosen crop. As a result, not all arable crops induce the same average amounts of glyphosate application. The quantities spread per hectare vary by up to threefold.

Table 2: Quantities of glyphosate on annual ‘arable crops’ according to SSP data.

NB: Glyphosate use on an intercrop is accorded to the crop which follows.

Species	Region	Total quantity of glyphosate (g)	Average quantity of glyphosate (g)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate (%)
Sunflower	All - 2011	179 663 953	263,0	226 814	0,33	1 331 531	1,95	13,3
Protein pea	All - 2011	25 496 634	159,9	34 428	0,22	447 950	2,81	6,4
Grain maize	All - 2011	194 529 247	132,2	220 001	0,15	4 249 282	2,89	4,3
Barley	All - 2011	166 848 573	126,3	244 543	0,19	2 654 889	2,01	6,3
Forage maize	All - 2011	132 203 078	123,1	163 446	0,15	3 189 271	2,97	4,2
Triticale	All - 2011	35 813 453	103,8	34 779	0,10	528 628	1,53	4,3
Oilseed rape	All - 2011	137 065 565	97,7	226 501	0,16	3 406 221	2,43	4,7
Durum wheat	All - 2011	31 152 045	89,8	45 757	0,13	615 096	1,77	4,5
Sugar beet	All - 2011	32 751 294	89,5	44 721	0,12	5 418 675	14,81	0,7
Soft wheat	All - 2011	389 485 556	84,8	532 894	0,12	9 689 327	2,11	3,8
Potato	All - 2011	8 283 386	58,3	9 333	0,07	619 205	4,36	1,3

Reading note: In 2011, 389,485,556g of glyphosate was spread on soft wheat crops. Soft wheat farmers used an average of 84.8g/ha during the 2011 cropping year. A total of 532,894 treatments were made with a product containing glyphosate, and on average, soft wheat farmers performed 0.12 treatments with a product containing glyphosate. The total number of herbicide treatments on soft wheat in 2011 was 9,689,327, or 2.11 herbicide treatments on average. On average, 3.8% of herbicide treatments on soft wheat were made with a product containing glyphosate.

3-2-2 Glyphosate use in France in arable crops according to the SSP 2011 and 2014 surveys

Overall, glyphosate use concerned 14% of the total area in 2011 and 15% in 2014. This value covers situations of a different nature since, in a limited number of cases (3-4%), glyphosate is used to destroy an area of permanent or temporary meadow, a little more frequently (13-16%) to destroy an intercrop cover and, in the vast majority of cases (more than three-quarters of situations), to destroy weeds in the absence of grassing or cover as a complement to a variety of tillage strategies.

The frequency of glyphosate use appears to be highly variable depending on the tillage strategy. In fact, less than 10% of systematically ploughed areas are involved in glyphosate use, compared with nearly 40% of areas under simplified cultivation techniques, and more than 60% of direct sowing areas in 2010-2011 (Figure 3). However, ploughing, whether systematic, frequent or occasional, concerns the majority of the arable area. As a result, nearly two-thirds of the areas affected by a glyphosate application will have been ploughed, at least occasionally, during the six years of monitoring (Figure 4).

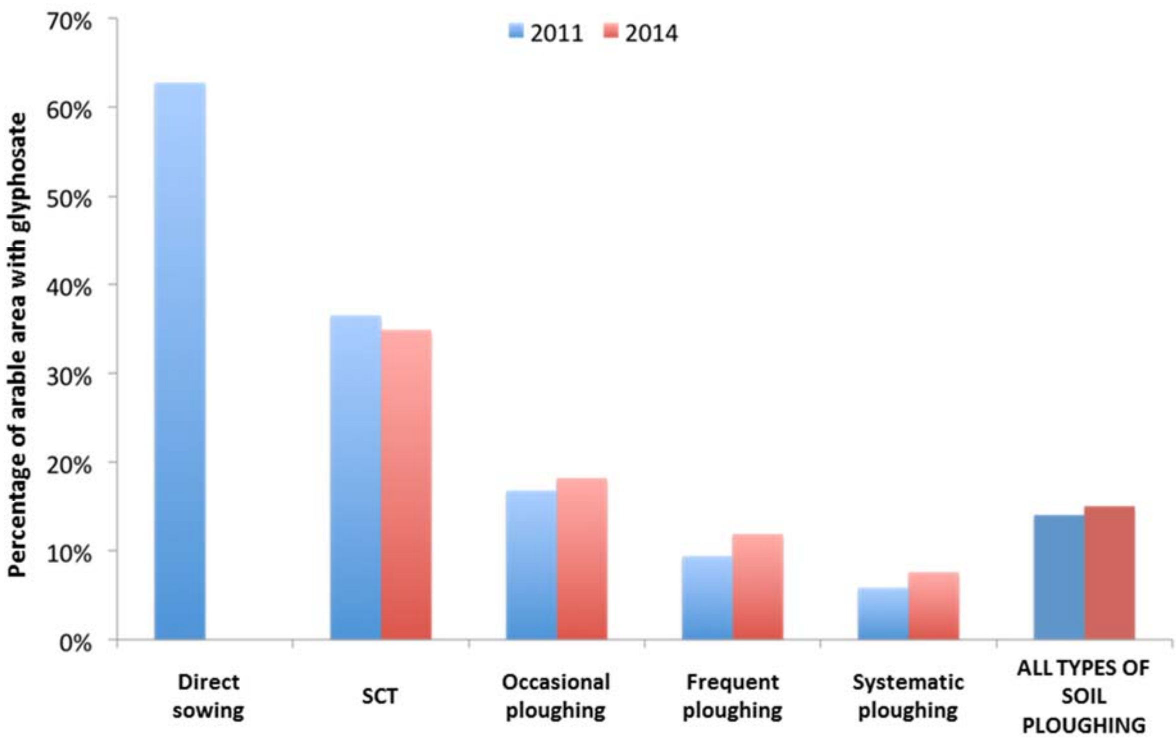


Figure 3: Percentage of arable area with glyphosate use in 2010-2011 and 2013-2014 respectively, according to tillage strategy. (Systematic ploughing signifies ploughing every year, Frequent ploughing is more than one year in two, Occasional ploughing is a maximum of one year in two, SCT (Simplified Cultivation Techniques) signifies no ploughing in six years but other tillage work in 2010-2011, and direct sowing no ploughing for six years and no other tillage in 2010-2011 apart from sowing. SCT and direct sowing cannot be distinguished in the partial 2014 survey, which covers no tillage interventions beyond ploughing).

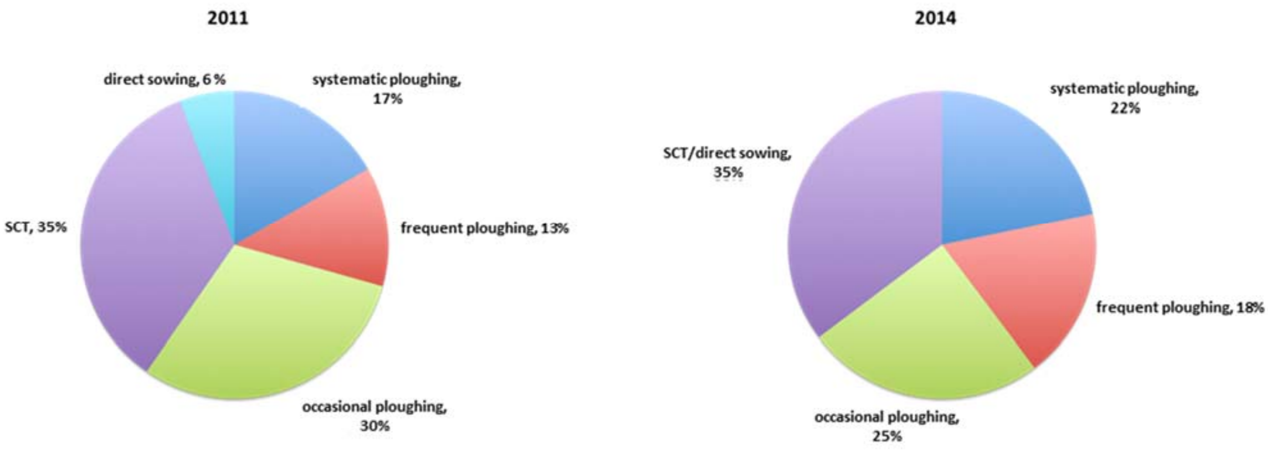


Figure 4: Distribution of arable land concerned by a glyphosate application in 2010-2011 and 2013-2014, according to tillage strategy. (Systematic ploughing signifies ploughing every year, Frequent ploughing is more than one year in two, Occasional ploughing is a maximum of one year in two, SCT *(Simplified Cultivation Techniques)* signifies no ploughing in six years but other tillage work in 2010-2011, and direct sowing (*semis direct*) no ploughing for six years and no other tillage in 2010-2011 apart from sowing. SCT and direct sowing cannot be distinguished in the partial 2014 survey, which covers no tillage interventions beyond ploughing).

When glyphosate is used, the survey does not show a difference in dose depending on the type of tillage. In general, the dose chosen for the application takes into account the situation; so large, well-established plants with a large root system are much more difficult to destroy and will require a higher dose than young seedlings.

Glyphosate use is significantly more frequent on fields receiving successions of oilseed rape and straw cereals, or sunflower and straw cereals (Table 2). Given the variation in rotations from one region to another, annual glyphosate use is not evenly distributed across France. A central band divides France (Figure 5), in which the percentage of the surface area receiving glyphosate varies between 17% and 30% (depending on the department), compared with 1% to 17% outside this area.

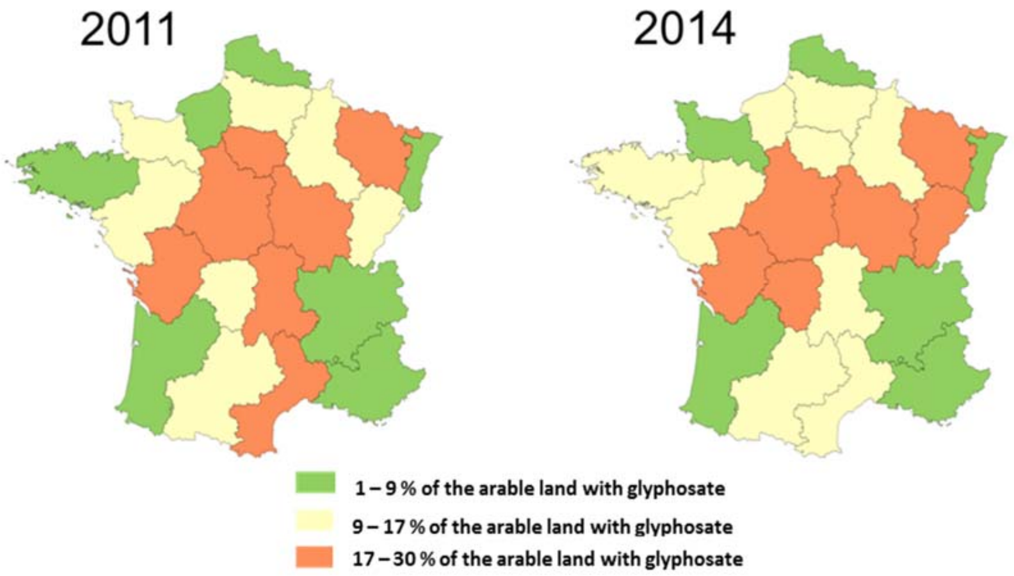


Figure 5: Distribution across France's former administrative regions according to the share of arable land receiving a glyphosate application during the growing seasons 2010-2011 and 2013-2014.

A recurring question is whether or not glyphosate can be substituted or supplemented with other herbicide applications during the cropping season, depending on whether or not there was intercropping prior to the establishment of the crop. Figure 6 shows that, within the different reported situations, the contrast between situations with and without glyphosate display values of between +0.4 and +0.9, indicating a supplement of the herbicide application when glyphosate is applied, there is no carry-over effect in either direction. This fact, found in the DEPHY itineraries (see the corresponding part of the report), underlines the role assigned to glyphosate in the destruction of cover and management of difficult flora including perennials during the intercrop period.

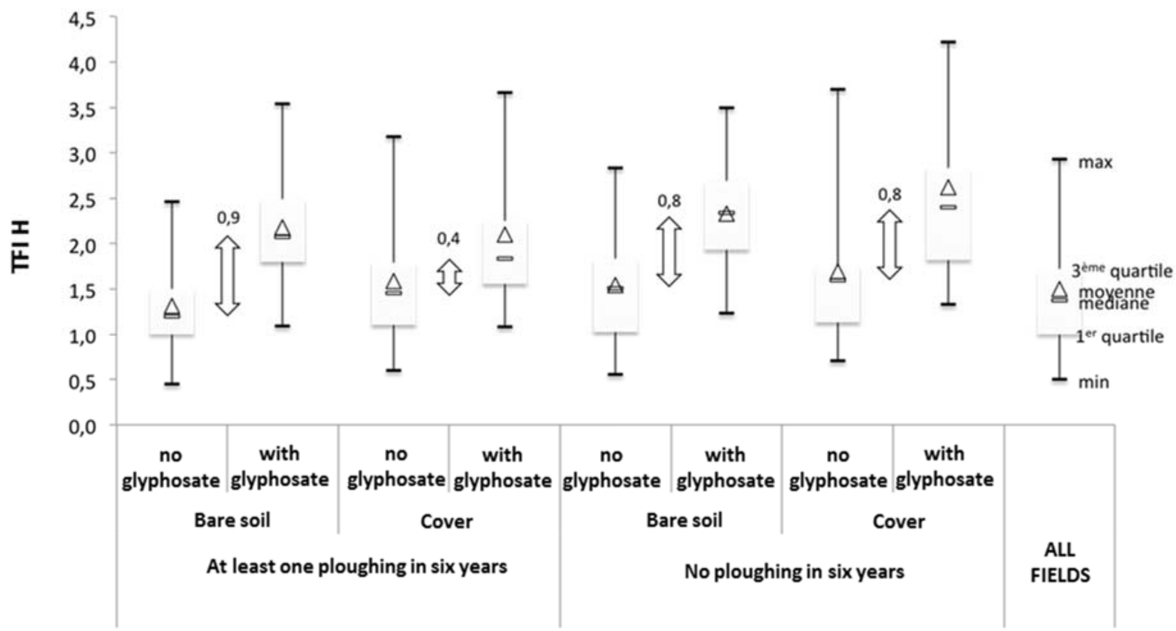


Figure 6: Comparison of the TFI H (Treatment Frequency Index for herbicides, including glyphosate) on the fields surveyed in 2010-2011, with or without a glyphosate application. Plots grouped according to the presence of at least one ploughing (or not) during the six years surveyed and according to the presence or not of a cover crop during the intercrop preceding the crop surveyed.

Finally, to conclude on the relationship between glyphosate use and tillage, we can observe a substitution between chemical weed control with glyphosate and a tillage intervention only in situations where the intercrop cover has been established. The difference of one passage found between these situations shows that a single mechanical intervention can replace the application of glyphosate to destroy the cover, the other interventions being in preparation for sowing.

3-2-3 Factors explaining the variability of the level of glyphosate use, from the DEPHY network

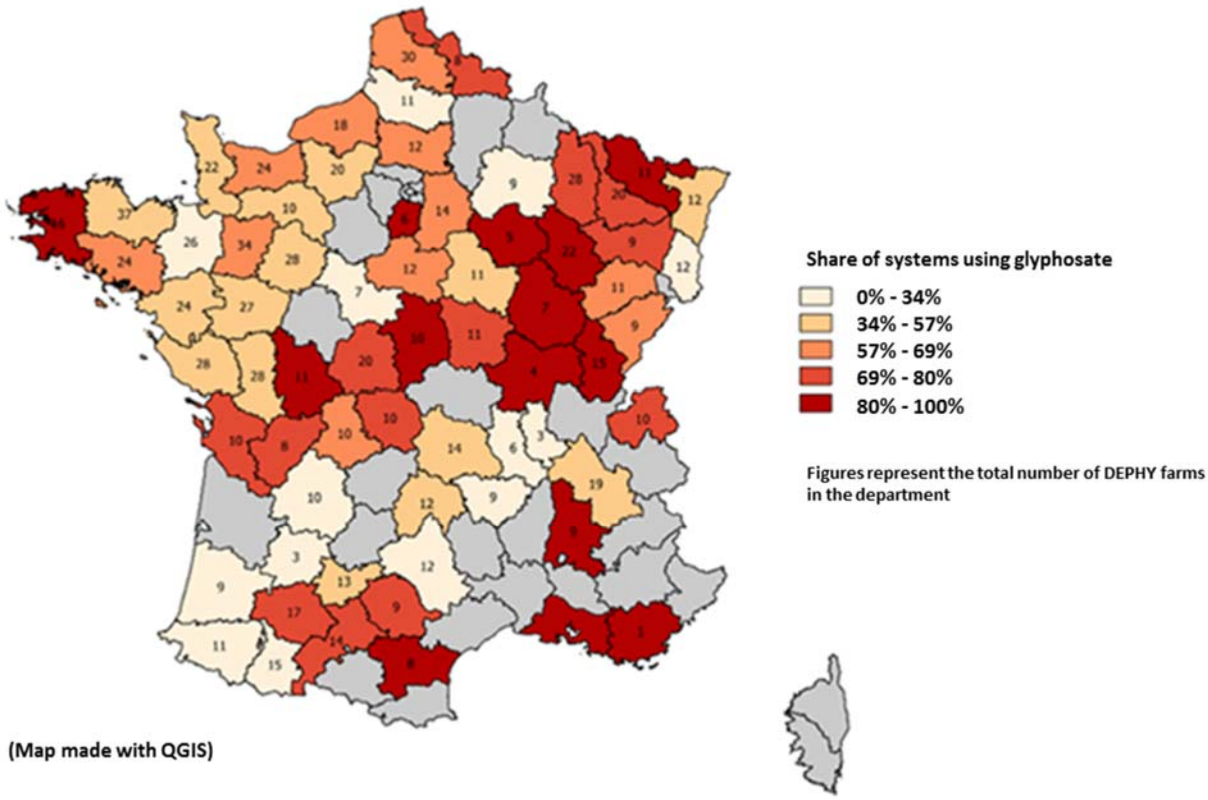


Figure 7: Map showing the level of glyphosate use on DEPHY farms for arable crops and the mixed polyculture-livestock sector. The departments are coloured according to the percentage of DEPHY farms using glyphosate. The numbers show the numbers of DEPHY farms in each department (note that this figure is low in some departments, particularly in the Var, which limits the robustness of the result).

- The frequency of glyphosate use is highest in cereal and oilseed production areas on shallow to intermediate soils, as well as in some south-western departments (Figure 7).
- This geographical depiction of glyphosate can be explained by the strong link between the use of glyphosate and reduced tillage. Glyphosate use is much less important for systems including ploughing (and less frequent when ploughing is common in the rotation) than for no-till systems. Among no-till systems, true and systematic no-till systems (no tillage intervention, see typology given in §2.2) use almost twice as much glyphosate as non-inverted, often superficial tillage systems. Since the tillage strategy is partly linked to farm size and the search for a reduction in working time, glyphosate tends to be used more on very large farms. These farms are more often managed without ploughing and glyphosate can be a lever to increase work flows in the preparation of seedbeds and makes it possible to sow large areas in a limited time.
- 100% of farmers adopting direct seeding strategies use glyphosate, which suggests that it is currently not possible to reconcile this type of strategy (also interesting for its environmental benefits) with a ban on glyphosate (*cf*. §3.6.1). Direct sowing under a cover crop represents only 2% of the farms, but they use 10% of the volume of glyphosate consumed in the DEPHY network for this sector. Around 50% of ploughed systems and 25% of systems using tillage

without soil inversion never use glyphosate, which suggests that it is possible, under appropriate conditions, to avoid the use of this product with this type of strategy. In these different situations, we do not have any information on the state of the weed population, especially on the level of risk generated by the seed population in the soil and the density of vegetative reproduction organs of perennial weeds.

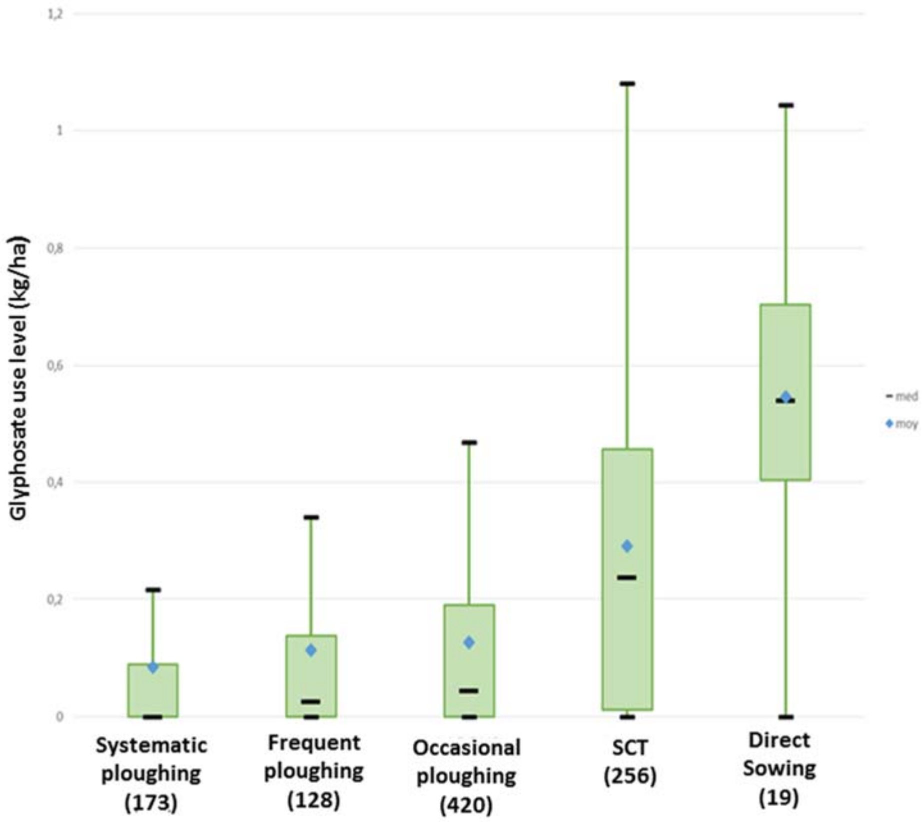


Figure 8: Distribution of the average glyphosate use level per hectare per year, depending on the type of tillage strategy. The number in brackets is the number of DEPHY farms. (SCT= Simplified Cultivation Techniques, no ploughing).

- Rotations based on oilseed rape and cereals (possibly with sunflower or seed legumes), which often correspond to soils with low to intermediate potential and are often managed without ploughing, are most frequently associated with glyphosate use.
- For systems which do not use ploughing, the frequency of glyphosate use is higher on clay soils than it is on lighter-textured soils.
- Herbicide use in crops is equal to or greater on farms that use glyphosate than those that do not. Glyphosate treatments during the intercrop period do not in any way limit the number of treatments during cultivation. Glyphosate treatments are an addition to the technical itinerary for the management of weed flora.

These elements thereby highlight some facilitating or aggravating factors: composition of the rotation, pedoclimatic situation, and the duration of the intercrop period affecting the stage of development reached by weeds etc.

Alternatives to glyphosate will therefore be presented in a structured manner according to the agronomic service for which glyphosate is used. The four main services identified are the control of perennial weeds, the destruction of temporary grasslands, the destruction of intercrop cover and cleaning before sowing of revegetated plots.

3-2-4 Glyphosate alternatives in arable crops, efficacy, feasibility and impact on farms

Preliminary remarks: Research by INRA, like that of other institutes, based on experimentation with innovative cropping systems or on the analysis of the diversity of farmers' practices, shows that combinations of technical levers are able to maintain low levels of weed infestation in crops, even in the absence of herbicide use. Under these conditions, the need to use herbicides during the growing season is reduced (Chikowo *et al*., 2009; Lechenet, 2017). Among the levers identified we find: the diversification of crop successions, particularly in terms of diversifying the planting period, the use of unsystematic ploughing to deeply bury the seeds of annual plants, shifts in sowing dates to avoid the periods of weed emergence, linked or not with the practice of false (stale) seedbeds, choosing varieties and species which are competitive and vigorous in their establishment phase, the sowing of 'companion' plants limiting the space available to weeds thereby reducing their growth, moderated fertilisation in certain crops, mechanical weeding during the growing season etc.

However, management strategies based on these levers respond to the challenge of an overall reduction in herbicide use, and are therefore different from those seeking to reduce glyphosate use because (i) they are generally not very effective on perennial weeds (which are the target for 25% of glyphosate treatments, according to the doses applied); (ii) they limit weed emergence in crops at sufficiently low densities so that competition harmful to the crop remains negligible, while glyphosate used during intercropping is intended to produce a weed-free field at the sowing date. The alternatives to glyphosate are therefore very specific and can be divided into the uses for which this molecule currently offers effective action:

- **Control of perennial weeds:**
    - The introduction of multi-annual temporary grasslands in the rotation, in particular lucerne. Repeated harvesting of lucerne depletes the underground reserves of perennials and effectively eradicates these weeds, particularly thistles (Meiss *et al*., 2010). However, it is difficult to generalise this alternative. It can be deployed on farms where herbivore livestock makes it possible to benefit from this fodder crop or where there is a nearby plant producing dried lucerne pellets.
    - Tillage during intercropping periods with adapted tools: stubble cultivation interventions are quite effective on dock; curved-toothed tools can remove the relatively shallow couch grass rhizomes and they can be left to dry on the soil surface provided the weather conditions are warm and dry. These approaches are therefore preferred in summer. These methods are not effective on thistle or bindweed. On quackgrass and dock, they can be satisfactory only if the level of the infestation is not too high.
    - Chemical weeding during cultivation: against perennials, this is the alternative which can be most generalised. In a number of cases, products effective for eliminating perennials have larger spectra, so chemical control of perennials during the growing season does not necessarily require additional treatments compared to chemical weed control itineraries for the usual weeds (annual and biennial). Furthermore, perennial weeds are quite often located in very marked spots in portions of the field. In the case of a specific treatment against perennials, localised treatments on these spots make it possible to significantly limit the volume of herbicide applied, provided that a precise means of locating these patches is available. An analysis of current practices shows that localised treatment practices are still not widespread, in particular because farmers are worried about not treating isolated weed plants which are difficult to locate and that the identification of outbreaks is not always

easy during the growing season. These small outbreaks can cause heavier infestations in subsequent years. The generalisation of a differentiated approach with the detection of weeds and localised weed control (chemical or mechanical) is therefore a major issue. However, these herbicides often have a good efficacy for the destruction of aerial vegetative organs but can quite frequently be partially defective in the destruction of underground reproductive organs. In addition, these chemical alternatives could be compromised if future changes in regulations are more restrictive on the use of herbicides during the growing season:

- On Canada thistle, products based on clopyralid, metsulfuron-methyl or auxinic hormones are effective and their marketing authorisation allows them to be used in many crops (cereals, maize, oilseed rape, beet etc.).
- On quackgrass, products based on sulfosulfuron or propoxycarbazone can be used in cereals, several foliar graminicides can be used in oilseed rape, pea, sunflower and maize.
- On dock, products based on fluroxypyr, metsulfuron or thifensulfuron can be used and are effective in cereals.
- On Aleppo sorghum, sulfonylurea products for use in maize are effective.
- Chemical control without glyphosate is certainly most difficult for bindweed: fluroxypyr (usable in cereals and maize) and dicamba (usable in maize) may have limited efficacy but generally do not provide eradication.

- **Destruction of grasslands**
  The alternative to glyphosate is tillage, involving either ploughing with the soil turned over, or several successive tillage interventions without turning. The fact that the majority of grassland destruction is currently done without the help of chemicals suggests that the alternative to glyphosate is generally feasible and will have little impact on farms.

- **Destruction of intercrop covers and the weeds growing there**
  There are alternatives to chemicals for the destruction of intercrop canopies, which also provide numerous ecosystem services:
  - Frost, in the regions of France which are cold enough in winter (roughly, the centre and north-east quarter), provided the species and genotypes of the cover crops chosen are sensitive to frost. However, (i) frost may be insufficient in some mild years, (ii) for autumn planting, frost alone is not sufficient because it occurs too late in relation to the sowing of the cash crop, (iii) in most cases, frost-resistant weeds which need to be destroyed develop with the intercrop cover. Only plant cover crops with high growth rates, capable of rapidly producing very high levels of biomass during the intercropping period, are likely to be sufficiently suffocating to regulate weeds, but these favourable situations are not always possible.
  - Mechanical interventions with tools such as chopper rollers (Rolo Faca, for example) made up of bars that break the stems make it possible to destroy cover plants, provided that sensitive species and genotypes have been chosen, in which breaking the stems actually stops plant growth and development. However, weeds that develop with the intercrop cover are only slightly affected by these mechanical interventions. Therefore, they must be controlled by canopy density. The choice of cover species must therefore be based on functional traits such as speed of growth and capacity to be destroyed by chopper roller. The work of Cordeau *et al*. (2017) shows the diversity of functional traits of species that can be used as cover crops. The work carried out under the CTPS (Permanent Technical Selection Committee) and the inter-sectional

commission on service plants also contributes to a better understanding of the services expected and offers a specific and varietal response.

- Tillage is the surest way of destroying plant cover, especially when annual weeds have developed in it. It can take the form of ploughing with turning of the soil or tillage without turning the soil using appropriate tools (for example, goose-foot tillage tools to destroy root systems under their regeneration zone). This can be an addition to other control methods when they have been insufficiently effective (on sown cover crops or weeds).

- **Cleaning revegetated plots before sowing of the following crop:**
  - With the removal of glufosinate, there will be virtually no alternative chemical weeding solution to glyphosate during the intercrop period (with the exception of dicamba before maize). Herbicides based on pelargonic acid (C9:0) are contact defoliants that benefit from a marketing authorisation for other uses, particularly in viticulture, with the classification of a biocontrol product. They could eventually be candidates, but with lower efficacy than glyphosate on perennials and, above all, a price that may drastically limit their use on a large scale.
  - The establishment of high-density plant canopies using species which are sensitive to both frost and chopper rollers may be a means to regulate weed development and volunteers from the previous crop, but its effectiveness on weed control is more often than not imperfect and the destruction of the sown cover may itself be a difficulty (see above).
  - Tillage, with or without turning of the soil, in preparing the soil for sowing the crop is therefore the main alternative to glyphosate. It may, depending on the case, require one or more additional passages compared to the technical itinerary using glyphosate, or a modification of the temporal sequence of interventions, with the positioning of the last intervention shortly before sowing (or even at the time of sowing using a combined tillage and seeding tool), without increasing the overall workload (see the discussion on the impacts of alternatives to glyphosate). These practices can make use of the false (stale) seedbed technique, which comprises of promoting the germination of weeds present in upmost soil layers then eliminating them with a mechanical intervention when the plants are at a very young stage. Repeated several times, this approach makes it possible to remove a large portion of weeds in the germination stage.

Tillage (with or without turning of the soil) therefore has a prominent place in alternatives to glyphosate. 100% of farmers in the DEPHY network who claim to have successfully abandoned the use of glyphosate on their farm cite tillage as the major lever that allowed them to achieve this result, possibly in combination with other levers, including the establishment of intercrop cover crops in good conditions.

However, not all farmland is equally suited to tillage. This will particularly be the case for soils which are difficult, superficial, easily waterlogged or stony. Similarly, soils high in clay content often take advantage of the rigours of winter and the combination of frosts and thaws to produce a quality seedbed. There may then be a legitimate reluctance to resume mechanical action just before spring sowing in order to get rid of a few weeds as growers may lose some of the benefits of winter. Finally, some areas are classified as being at a high risk of erosion and tillage may be discouraged. Logically, direct sowing techniques under a cover crop will often be preferred to limit the erosion risk. Intensifying tillage to compensate for the withdrawal of glyphosate may then be problematic.

3-2-5 Evaluation of the impacts of alternatives to glyphosate on farms' economic and environmental performance

These impacts were evaluated on the basis of the diversity of practices in the DEPHY farms network, by comparing various indicators (yield, number of tillage interventions, mechanisation costs, level of herbicide use excluding glyphosate, energy consumption and greenhouse gas emissions), for very similar groups of farms using glyphosate versus those that never use it. In order to compare only very similar farms, the 996 farms were stratified into homogeneous groups from the point of view of (i) the yield potential determined by the pedoclimate, (ii) the link or not with livestock on the farm, ((iii) whether or not there is access to irrigation, (iv) access to the possibility of cultivating high value-added industrial crops (such as beet or potato), in connection with the local agro-processing industry, (v) the type of crop succession (cereals-maize, oilseed rape-cereals, cereals- oilseed rape-sunflower, cereals-oilseed rape-legumes, maize monocropping, rotations with industrial crops, rotations with temporary grasslands etc.), and (vi) from the point of view of the tillage strategy (with or without ploughing).

- Unsurprisingly (because farmers still achieve their goal of producing a weed-free plot ready for sowing, whether that is with glyphosate or alternative methods), whether or not glyphosate is used has no impact on the yield of the next crop or the quality of the harvested products.
- Systems that do not use ploughing or glyphosate tend to have more intense tillage itineraries (4 out of 5 cases), usually with an extra passage each year (Figure 9). On the other hand, this increase in the number of tillage interventions is rarely observed in systems with at least occasional ploughing (2 out of 7 cases).

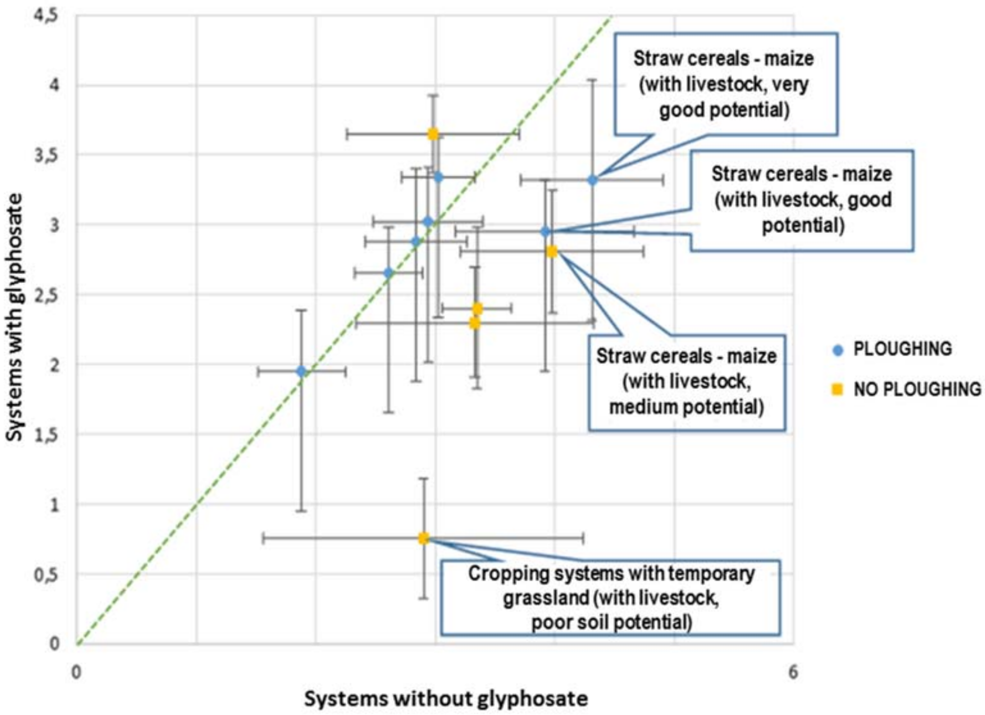


Figure 9: Comparison of the number of tillage interventions during the intercrop period, for systems with glyphosate use versus those without. Each point corresponds to a group of arable farms with the same production context, same type of crop succession and same type of tillage strategy (ploughing versus no ploughing). The horizontal and vertical bars represent a standard deviation.

- This increase in the number of tillage interventions in the absence of glyphosate does not significantly affect mechanisation costs, which remain similar for systems with glyphosate use versus those without, in similar production contexts (Figure 10).

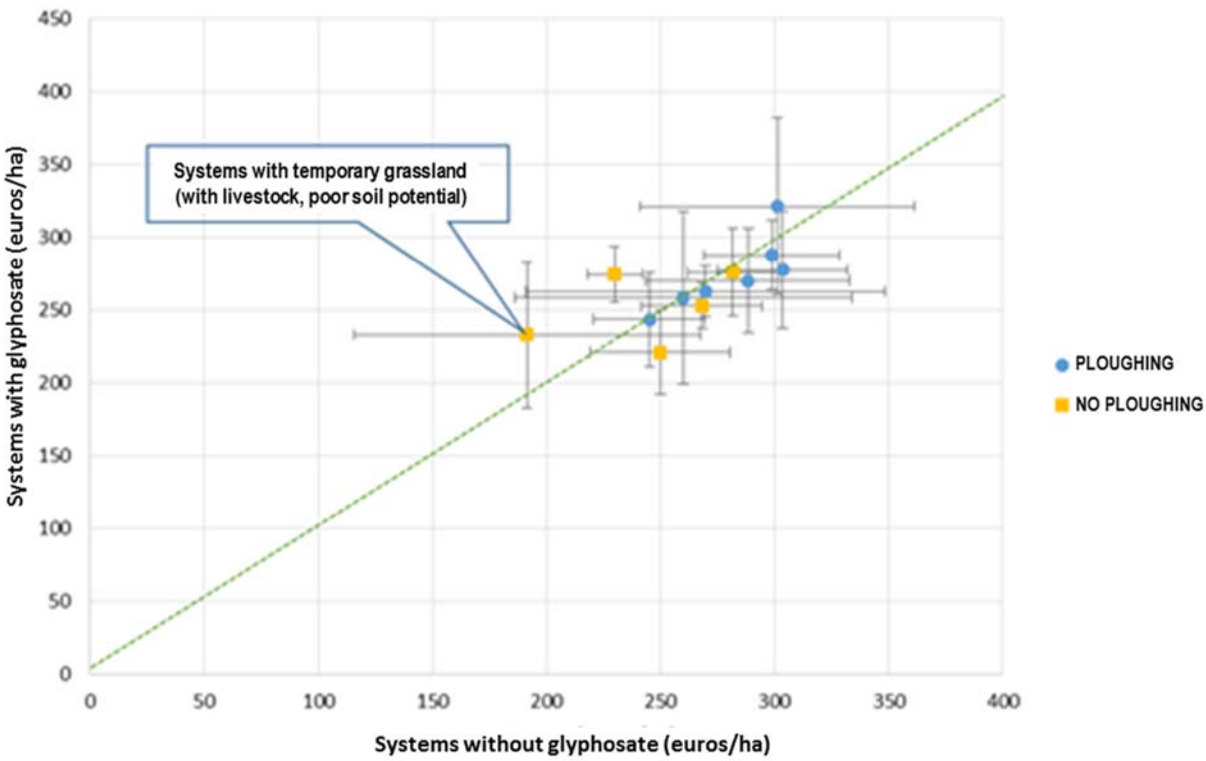


Figure 10: Comparison of the mechanisation costs for DEPHY network systems with glyphosate use versus those without. Each point corresponds to a group of arable farms with the same production context, same type of crop succession and same type of tillage strategy (ploughing versus no ploughing). The horizontal and vertical bars represent a standard deviation.

- However, the fact of using or not using glyphosate can affect the date when tillage operations are completed, with more systematic passages shortly before sowing to destroy weeds (and volunteers) if glyphosate is not used. This can affect workflows in seedbed preparation and sowing, which may pose organisational difficulties on large farms with little diversity in their crops and many hectares to plant at the same time. This is particularly the case for farms on shallow clay-limestone soils, with low to medium yield potentials, on which the margins achieved per hectare are limited, which requires farmers to manage large areas in order to generate sufficient agricultural income. On these types of farms, which are currently those which use the most glyphosate, abandoning the glyphosate approach will result in a tendency towards a diversification in the crops sown to better stagger sowing operations (a positive effect agronomically, but not easy to achieve in practice in these kinds of environments), or a need for adjustments in tillage and sowing equipment to increase work rates. In addition, for spring sowing on clay soils, farmers may be reluctant to work the soil just prior to sowing the crop because of concerns about damaging the highly favourable seedbed structure naturally produced by alternate rain/drying and freezing/thawing during winter. Tillage to remove plants that develop in the intercrop may then produce clods which are unfavourable for successful sowing if they are too deep.

- We can observe no relationship between the weeding itinerary during the intercrop period for seedbed preparation and the chemical weed control itinerary during cultivation. Given the same production context and type of tillage, DEPHY farms that use glyphosate during the intercrop period have levels of chemical weed control during cultivation that are equivalent to, or even greater than, those farms which do not use glyphosate. Glyphosate use therefore tends to increase the costs due to chemical weeding during cultivation. Perennial weeds, which account for approximately 10% of glyphosate treatments, are managed by other means by farmers who do not use glyphosate, without it being possible to identify an increase in the costs attributable to these alternative methods.
- Given the same production context and tillage strategy, we can observe no impact of the use versus non-use of glyphosate on direct energy consumption (fuel consumption) and indirect consumption (manufacturing of inputs) (Figure 11)

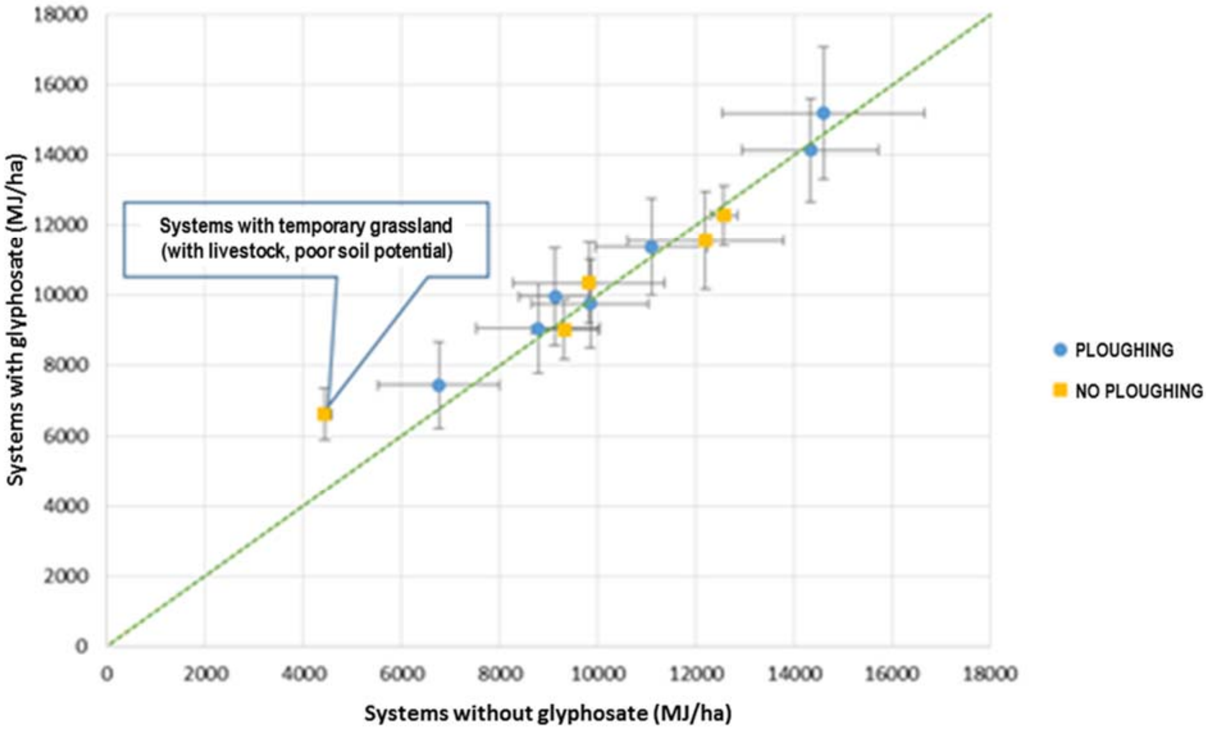


Figure 11: Comparison of energy consumption (direct and indirect, estimated using the GES'TIM method) for DEPHY network systems with glyphosate use versus those without. Each point corresponds to a group of arable farms with the same production context, same type of crop succession and same type of tillage strategy (ploughing versus no ploughing). The horizontal and vertical bars represent a standard deviation.

In short, the comparison of arable crop systems described in DEPHY farms using glyphosate versus those not using it in similar production contexts, shows that the alternatives to glyphosate, mainly tillage in preparation for sowing, tends to increase the number of tillage interventions in some situations (in other cases, it changes only the date when these interventions are conducted), without significantly affecting mechanisation costs or energy consumption. The fact that glyphosate is not used does not significantly modify weeding costs during cultivation. On the other hand, using glyphosate makes it possible to accelerate the work rate in preparation for sowing and its withdrawal could affect the organisation of work on large farms with little diversity in the crops grown.

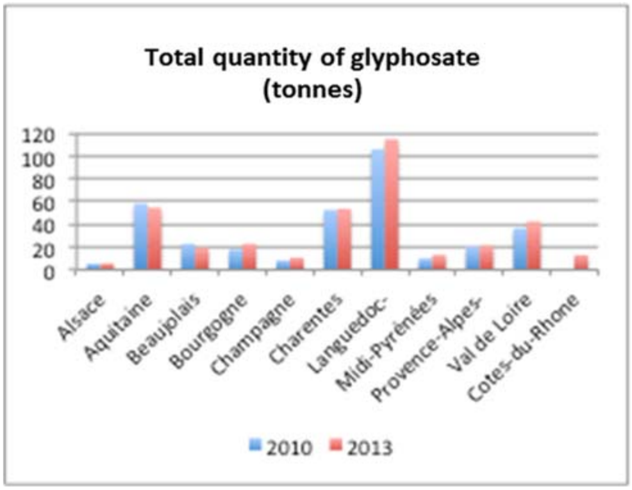
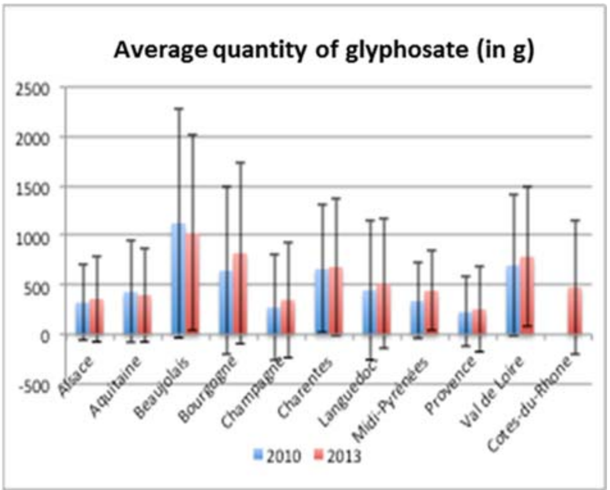
However, the replacement of glyphosate with the reintroduction of tillage in systems where there is currently no tillage and a strategy of direct sowing under a cover crop would mark a real break and calls into question an innovative agronomic strategy and its related environmental benefits (see paragraph 3.6 on orphan situations).

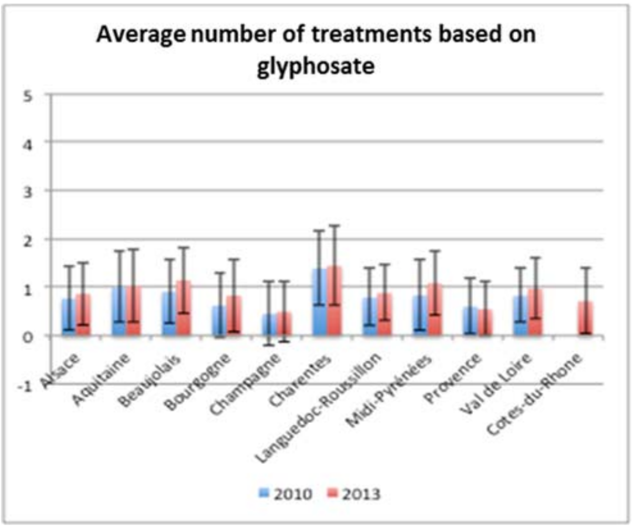
The diversity of situations found in the DEPHY network covers situations both with and without glyphosate use. To give full value to the comparison, the approach deployed was based on stratified groupings and used only groups of 10 or more farms. However, some variables which can influence glyphosate dependence and the ease of overcoming it are not available. First and foremost we think of the weed seed bank in the soil, the time constraints for interventions and the mental load that may result from the choice of more technical practices. The new approach will require more observation and interventions will be deployed over a shorter timeframe. So, it seems important to stress that the very existence of farms which are not dependent on glyphosate provides little information on the trajectories that led them to this situation, as well as on the transition time required to master the move to glyphosate-free production.

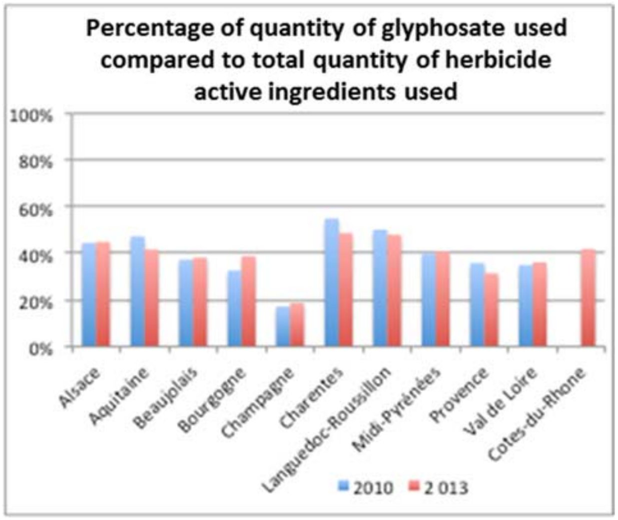
3-3 Glyphosate use in viticulture

3-3-1 Quantities of glyphosate used in viticulture

In succession we analyse the SSP and DEPHY farm databases.

	
A	B





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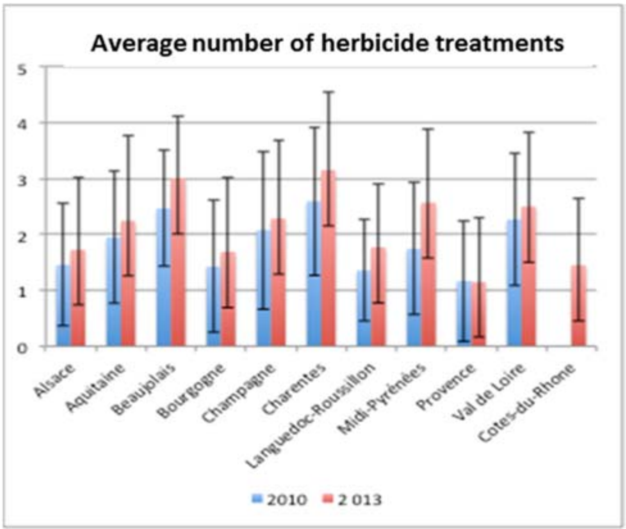
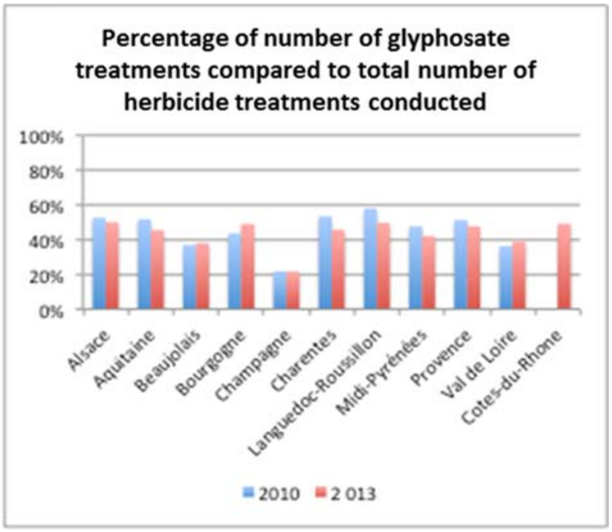
D





E

F

Figure 12: Distribution of the quantities of glyphosate used, and the number of passages in vines for 2010 and 2013 in France's wine-growing regions (source: SSP - Agreste - Survey on phytosanitary practices in viticulture, joint panel of 2010 and 2013 surveys of 4,856 plots), in absolute terms (Figures A B, and C), and relative to other herbicide use (Figures D, E, F). The bars indicate the standard deviations.

For the two years studied, the proportion of glyphosate (in quantity) compared to all herbicides used oscillates between 17% and 19% in Champagne in 2010 and in 2013, reaching 49% and 55% in Charentes in 2010 and 2013 (Figure 12D). For the two years studied, the number of applications of glyphosate compared to the total number of herbicide applications varies between 22% in Champagne in 2010 and 2013, reaching 50% and 58% in Alsace and in Languedoc in 2013 (Figure 12F). In Champagne, the quantities of glyphosate used are the lowest and are applied in a few passages (Figures 12A and 12C). Other soil maintenance strategies seem to be favoured.

Between 2010 and 2013, the total quantity of glyphosate spread on vineyards in France increased by about 10% (from 337 to 371 tonnes, Figure 12A). In most vineyards, the quantities of glyphosate used increased between 2010 and 2013, except in Aquitaine and Beaujolais, where the quantities were reduced by 6% and 16% respectively between the two years. The maximum increase between 2010 and 2013 is recorded for the vineyards of Midi-Pyrénées, where it climbed by about 30% (Figure 12A).

Wine-growers used an average of 471.4 g/ha/yr of glyphosate during the 2010 season and an average of 510.8 g/ha/yr of glyphosate during 2013, an increase of 8.4% (Figure 12B). In most vineyards, the quantities of glyphosate used increased between 2010 and 2013, except in Aquitaine and Beaujolais, where the quantities decreased between 7% and 9% between the two years. The largest increase between 2010 and 2013 was for the vineyards in Midi-Pyrénées, climbing by about 30%. Due to the large fluctuations observed within each area of vineyards and wine-growing region, it remains difficult to extract significant trends that can be explained by geography alone. A combination of regulatory factors with the abolition of certain marketing authorisations and climatic particularities can also be invoked as partially responsible for these erratic developments.

On average, wine-growers conducted 0.86 treatments with a product containing glyphosate in 2010 and 0.93 treatments in 2013 (Figure 12C). As with the quantities of glyphosate applied, there is no real geography to glyphosate use in view of the very high standard deviations in all vineyards, and this often corresponds to soil maintenance methods that are mixed, combining chemical weed control, grass cover and/or tillage distributed differentially in the plot space (under row and inter-row) and over time (winter, spring and summer periods). The same is true for the number of herbicide treatments in general, apart from the fact that the values oscillate between an average of 1 to 3 treatments per year (Figure 12E).

Table 3: Percentage of total French wine-growing areas treated with glyphosate in 2006 and 2010 compared to other herbicide active ingredients used (source: number 288 October 2012 SSP - Agreste - Survey on Phytosanitary Practices in Viticulture, Ambiaud, 2015).

Smaller surface area treated with glyphosate
active ingredients used in 2010 and 2006
for weeding wine grape vines

Herbicide active ingredient	Share of surface area treated (%)	
	2010	2006
Glyphosate (isopropylamine salt)	57	70
Flazasulfuron	28	19
Aminotriazole	13	20
Carfentrazone etyhyl	9	3
Oxyfluorfen	8	1
Flumioxazine	11	13
Ammonium glufosinate	9	10
Propyzamide	7	1
Glyphosate (ammonium salt)	6	5
Ammonium Thiocyanate	5	19
Oryzalin	4	8
Diuron [1]	0	21

1. Marketing authorisation withdrawn in 2007.
Note: of the area treated with a herbicide, 57% were weeded with glyphosate

Source: SSP - Agreste - Survey of phytosanitary practices in viticulture

Table 3 provides information on changes in glyphosate use: glyphosate levels appear to have decreased between 2006 and 2010 and slightly increased by 2013. After analysis, the results of the 2016 SSP survey will be able to confirm whether the trend in glyphosate use has reached a plateau in recent years.

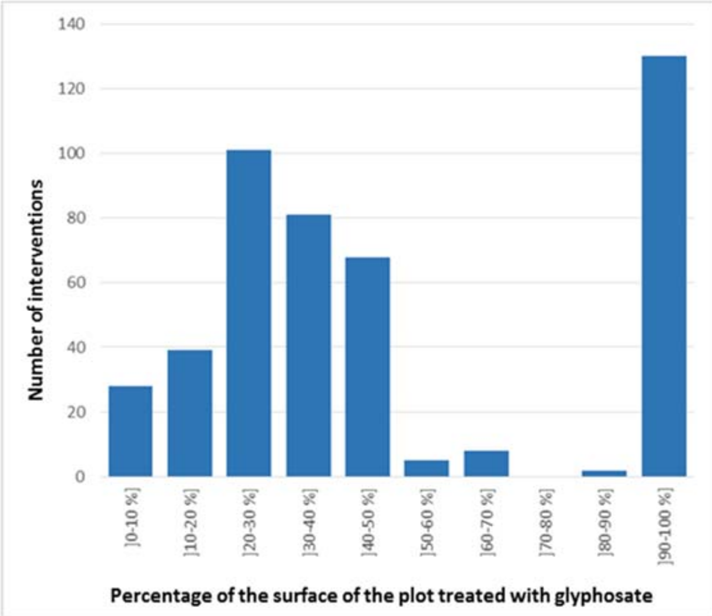


Figure 13: Number of interventions according to the percentage of the surface of the plot treated with glyphosate (source: point zeros in the DEPHY farm viticulture database).

The DEPHY farm network's database, although less representative than the SSP database, confirms some information: a large proportion of French vineyards use glyphosate only for soil maintenance under the row. In fact, only 28% of the plots in the DEPHY farm database are treated in full with glyphosate: i.e. under all the vine rows and in all of the inter-rows (Figure 13).

Some 36% of conventional DEPHY farm vines were treated at least once during the three years described in the initial technical itineraries provided when they joined the network. The average dose of glyphosate users was 677 g/ha/yr (an average of 240 g/ha/yr for all conventional vineyards, both users and non-users of glyphosate). In viticulture, the DEPHY network used less glyphosate when joining the network than the national distribution of this herbicide (in contrast to arable crops). It should be noted that the DEPHY network is not representative of French vineyards, neither in its geographical distribution, nor in any other descriptive criterion of vineyards and plots. The farms in the DEPHY network are volunteers, very often already involved in approaches for reducing inputs, and often already highly aware of the environmental impacts of viticultural practices.

In the DEPHY network, only 28% of glyphosate treatments were applied 'in full' across the entire surface area of the vines. In 72% of cases, the treatment is localised under the row or on one inter-row in two. In the majority of cases, the area treated is between 20% and 50% of the total area. The proportion of the area treated during each passage varies with the type of vine, the area being smaller for vines with large spacing between the rows than for vines with small spacing. This is explained by the greater ease of mechanical maintenance in vineyards with large spacing.

3-3-2 Alternatives to glyphosate in viticulture, efficacy, feasibility and impact on farms

A first track could be based on an adaptation of the maintenance method according to a threshold of weed nuisance. This concerns both intervention dates (i.e. winter and spring) and space (i.e. below the rows and between the rows) (Leather *et al*., 2017). A second track is to try and integrate the positive role that weed flora can play in the balance of agroecosystems. The presence of weeds, below a threshold damaging to the vines, can favour the preservation or re-emergence of a better ecological sustainability and regulation of pathogens (Pocock *et al*., 2011; Rollin *et al*., 2017). A wide range of soil management methods offering an alternative to glyphosate use has been described, either covering the entire plot or partially below the rows and/or the inter-rows. These approaches are based on chemical and mechanical weeding strategies, permanent or temporary grassing and mixed methods contrasting row and inter-row treatments or one row in two etc. Soil maintenance methods in viticulture are already highly diverse and proven in French vineyards (Mailly *et al*., 2017). We provide an illustration in Table 4 and Figure 14 below.

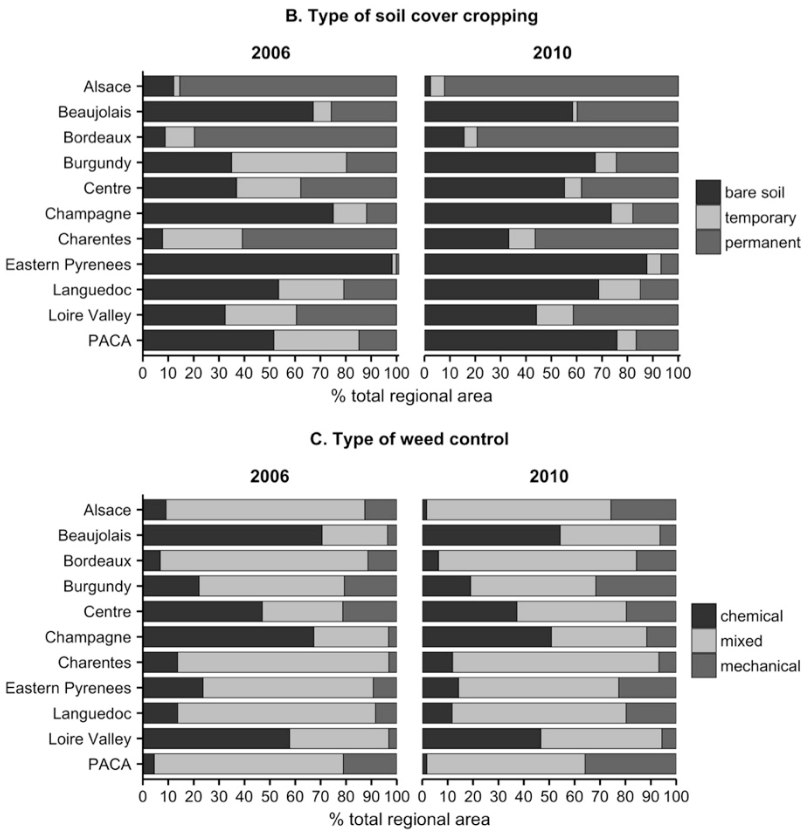


Figure 14: Types of soil cover (B) and type of weed control (C) in 11 French wine regions in 2006 and 2010 (Mailly *et al*., 2017). Data are expressed as a percentage of the regional average for each of the regions studied (see Table 4 for definitions).

We have analysed the existing types of soil maintenance in French vineyards. In light of these results, we see that types of temporary and permanent soil cover (Figure 14B) can be dominant compared to bare soils, which can lead to water erosion problems in vineyards on steep slopes. Figure 14C highlights the change between 2006 and 2010 with a growing share of mechanical or mixed weeding. This evolution can be seen across all French vineyards.

The classification below illustrates many possibilities for the combination of techniques (chemical weeding, grassing and tillage) both over time (winter, spring and summer) and space (under the row and in the inter-row) which wine-growers can choose in order to arrive at a soil maintenance method that best suits their agro-climatic constraints, as well as their objectives concerning yield and quality of the grapes harvested. Figure 15 illustrates the effort to highlight and disseminate alternative management approaches to weed flora.

Table 4: Characteristics of types of soil maintenance in vineyard plots using herbicides (from Mailly *et al*., 2017).

Name of variable	Description of variable	Form of variable	Description of method
Soil covered	Type of soil cover (B)	Permanent	Soil of the vine plot is covered by flora native to the plot or sown with grass which covers the soil throughout the growing year
		Temporary	Soil of the vine plot is covered by flora native to the plot or sown with grass which covers the soil for part of the growing year
		Bare soil	Soil of the vine plot is bare throughout the growing year
Bare soil	Type of weed control (C)	Chemical	The soil of the plot is weeded chemically either only under the vine rows, or between the vine rows, or across the whole plot
		Mechanical	The soil of the plot is worked mechanically either only under the vine rows, or between the vine rows, or across the whole plot
		Mixed	The soil of the plot is maintained by a combination of chemical weeding and mechanical work either in time or space and only under the vine rows, or between the vine rows, or across the entire plot

It is advisable to choose the soil maintenance strategy for under the row or in the inter-row according to the precocity of the grape variety, the plot's vigour and the plot's hydro-nitrogen constraints. Plot vigour is the result of the vigour conferred by the rootstock, the soil's physicochemical characteristics and the practices in the viticulturist's technical itinerary (Coulon-Leroy *et al*., 2013; Coulon-Leroy *et al*., 2012)

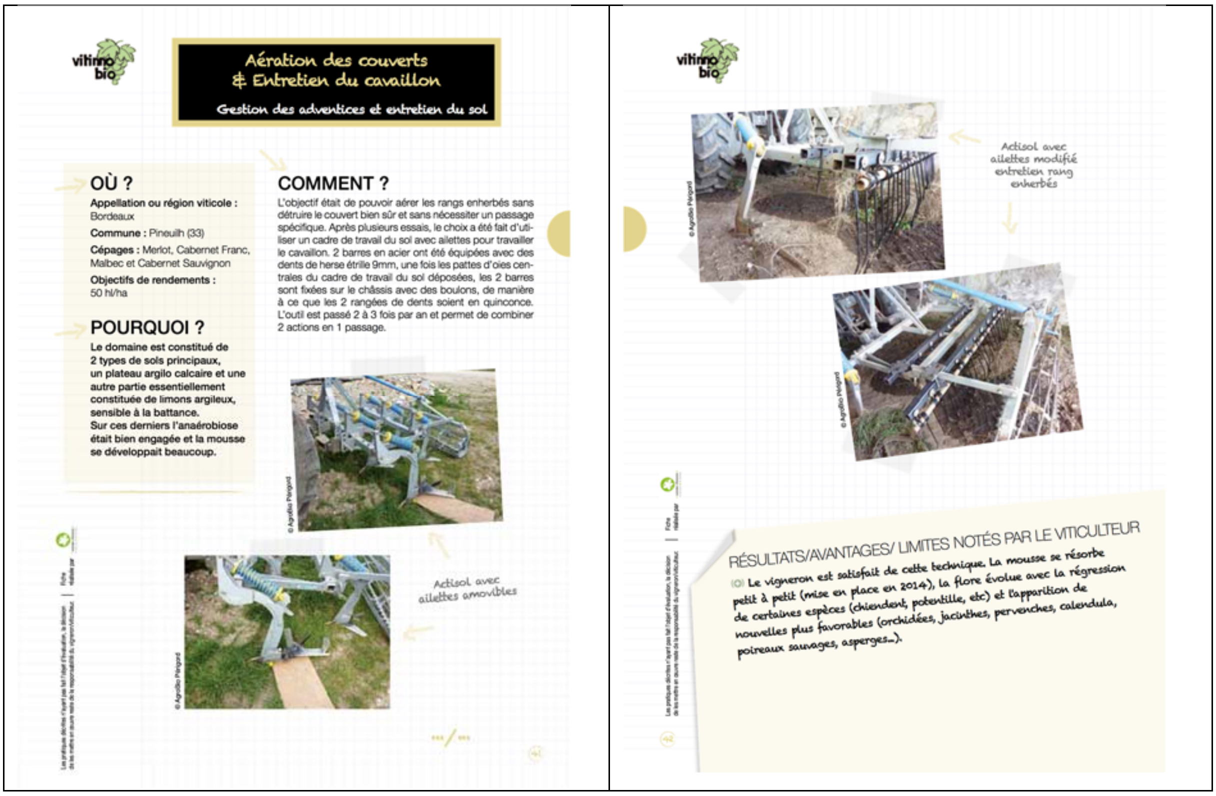


Figure 15: Illustration of alternative weeding practices to control weed flora in viticulture. Extracted from the booklet published at the end of Casdar No.5322 VITINOBIO.

3-3-3 Evaluation of the impacts of alternatives to glyphosate on vineyard economic and environmental performance

A foreseeable consequence of a regulatory change to withdraw glyphosate will be to create a domino effect on the requirement to review the perimeters of the specifications to take into account the foreseeable changes in soil maintenance practices as well as the induced changes in grassing and possible irrigation practices.

The other consequences will affect wine-growers more directly. In particular, it will also be necessary to quantify the **extra economic cost** relative to the system of marketing and promoting the wines, **but also the potential profit** that such a differentiation could induce. We must also estimate the **additional labour costs**. This integrates different dimensions: (i) the training and recruitment of a qualified workforce for driving agricultural machinery and operating tillage and grass maintenance tools, (ii) the increase in the need for labour during the period of heavy workloads, between April and July, and the associated costs, (iii) the integration of this new temporary workforce into the work organisation of the wine company. In addition, it’s necessary to train employees and managers in new management methods and the organisation of work within the company.

Finally, in terms of organisation and support, it is necessary to provide technical support for the agronomic diagnosis of the plot in order to choose the best soil maintenance solution in accordance with the quantitative and qualitative performance objectives for the plot. This technical support will also have a cost for the winery or its professional environment. Table 5 shows the perception of alternatives among the actors interviewed.

Table 5: Analysis of the ease of implementation of alternatives according to the nomenclature used in the DEPHY networks.

Technology Readiness Level
A: already available on the market
B: efficacy shown in a number of cases
C: method validated in particular experimental conditions
D: concept proved, period of active research
E: low level, basic principles

Efficacy
From A effective to E low efficacy

Ease of introduction
From A easy and economically viable to E difficult to implement

A or B "Green"
C "Yellow"
D "Orange"
E "Red"

	Inter-row maintenance			Row maintenance								
Technology Readiness Level	Glyphosate	Tillage	Plant cover	Glyphosate	Chemical control (other a.i.)	Tillage	Mechanically mowed cover	Robot mowed cover	Pasture cover	Mulch	Biocontrol produc	Thermal weeding
Technological maturity	A	A	A	A	A	A	C	D	E	C	A	C
Efficacy	A	A	A	A	D	A	C	C	E	D	D	D
Feasibility	A	B	B	A	A	C	D	C	E	D	A	E

In conclusion, a wide variety of solutions coexist in each wine-growing region. The choice of a plot's soil maintenance method will be based on agro-climatic conditions, quantitative and qualitative yield objectives, and an environmental balance that will also benefit other practices in the technical itinerary, which comprises the rest of the phytosanitary programme, work on growing vines and harvesting.

Only i) situations involving terraced crops and very stony soils, and ii) producers for the bulk market show a major tendency to resort to chemical treatments to control flora.

3-4 Glyphosate use in arboriculture

3-4-1 Usage data

An overall comparison underlines the unrepresentative nature of DEPHY's arboriculture network, linked to the limited number of farmers who have committed to the system and especially to the dynamics underway in the sector at the time the DEPHY network was created. Indeed, 30% of the farms in the network are organic or in transition to organic production. In addition, some crops have little or no representation: olive, cherry and nuts.

The latest surveys on practices were conducted in 2012 and 2015. As for glyphosate use, this ranges from around 20 tonnes for apple and pear orchards and about four tonnes for cherry orchards. In descending order in 2015, and taking into account the surface area concerned, apricot, peach and plum occupy intermediate situations. The average glyphosate consumption in orchards ranges from 480 g/ha/yr to 1,000 g/ha/yr.

Data from DEPHY orchards at the time they entered the network (mostly between 2009 and 2011) are consistent with national surveys. Glyphosate represented 38% of the weeding actions carried out by the 131 farms surveyed (i.e. 527 interventions out of the 1,402 recorded), with an average TFI of 1.75. Expressed in TFI, glyphosate accounted for 50% of the herbicides used. The regulatory changes which led to the withdrawal of a few herbicides (some of which will only come in to effect in 2018) and restrictions on use suggest, however, that these values in reality are rather below current levels. The withdrawal of aminotriazole at the end of 2015 is an illustration of the partial recourse to increased glyphosate use.

A significant portion of DEPHY network orchards (83%) were treated with glyphosate at least once in the three years of practices described on their entry into the network. Treatment rates ranged from 260 g/ha to more than 1,500 g/ha. These values are consistent with those of national SSP surveys. Only 27% of orchards were treated in full (apple, peach and apricot). Because of localised treatments on 33% to 73% of the surface area and the variability in the frequency of treatments, the variability of the quantities of active ingredient applied per hectare per year is wider than the variability of the dose by treatment, and ranges from 62g g/ha/yr to 3,600 g/ha/yr. The amounts of glyphosate applied vary more between orchards of the same fruit species than between species.

3-4-2 Alternative practices and their additional costs

To illustrate this section, we have used the example described in the German report detailing the situation of an apple orchard. We have chosen this example because it illustrates two potential sources of the extra cost generated by the withdrawal of glyphosate:

- The first is direct due to the implementation of mechanical or manual maintenance of vegetation, which can be economically difficult. It can lead to an increase in other risks (maintenance of other pest populations in the plot such as aphids and increased tree damage caused by voles etc.).
- The second is by affecting the size of the fruit produced, which can lead to downgrades on the market and therefore to a reduction in the producer’s remuneration.

Table 6 is taken from a summary produced by Germany’s Julius Kühn Institut (Kehlenbeck *et al*., 2015).

Table 6: Permanent apple production - hypotheses relating to management and effects on yield. Translated from a report by the Julius Kühn Institut (Kehlenbeck *et al*., 2015).

Installation	3,000 trees/ha on M9 rootstock, 20-year lifespan (KTBL, 2010)	
Production price	350 €/t (indirect sales via producer organisations, marketing costs already deducted, KTBL, 2010)	
Yield from start	Year 1: 3 t/ha, year 2: 12 t/ha, year 3: 26 t/ha, year 4: 32 t/ha, years 5-20: 39 t/ha (KTBL, 2010)	
	Variant with glyphosate	**Variant without glyphosate**
	In the variant with glyphosate, weed control comprises two applications of Roundup Power Flex in quantities of 3.75 l/ha at a price of €9.9 per litre. The authorisation specifies that a change of product is necessary between the	In the variant without glyphosate, weed control is carried out mechanically, according to the organic production principles corresponding to KTBL information. All other influences

Weed control	two uses. For the sake of simplicity, we assume here the use of an identical product (note: authorisation according to the BVL database, consulted on 03.03.15. Price: Agravis 2014 price list, price per litre in the largest container possible, 640 litres). Weed control occurs in 75% of cases only in tree rows (FREIER *et al*., 2014). We assume that 33% of the surface is treated. The spreading cost is estimated at €36.43 per ha and passage and is carried out using a tractor for planting (49-59 kW) with an added 600 litre spraying device with herbicide spray for tree rows. Wages are assumed to be €17.50 per hour. An annual mulch is also taken into account. According to KTBL (2010), the estimated hourly wage is €17.50 per hour and €276 per hectare.	correspond to those of conventional apple production. Mechanical weed control includes the treatment of tree rows with and without mulch, as well as the use of a manual hoe. According to KTBL (2010), the following operations can be assigned to weed control: **Year 1:** 5 x treatment of tree rows with mulch 1 x treatment of tree rows without mulch 1 x manual hoe **From year 2:** 5 x treatment of tree rows with mulch 1 x treatment of tree rows without mulch 2 x manual hoe
Yield loss	None	A yield reduction of 0 to 5% was assumed in new plantations because of the potential harm to young trees caused by mechanical weed control (years 1 to 4). From year 5, we have assumed full equivalence in efficacy with no loss in performance (expert estimate).

Compared to the situation described by the German institute, the French situation has some points in common but also some differences.

1) What is similar: chemical weeding practices account for about one-third of the weeded area in apple orchards and the total herbicide TFI is in the order of 1 (this is low compared to all the plant protection products applied in arboriculture, but the environmental impact can be high because it is applied on more or less bare soil); glyphosate is part of more or less every strategy.
2) What differs from the German situation:
   a) Orchard equipment

   The orchards are described as typical of northern Europe (3,000 trees/ha) but planting densities are lower in France (more like 2,000 trees/ha, or even less in organic and semi-extensive systems); these differences in density have no impact on reported yields, which are close to those found in France (varying according to soil and variety).
   The main difference is irrigation. This is widespread in all production areas in France except in the north, taking the form of localised irrigation using pipes on the ground. However, mechanical weeding cannot immediately take place in an orchard when there is an irrigation system on the ground; the system must be raised to allow mechanical weeding tools or Herbanet-type tools to pass. This is more easily organised at planting or requires adapting the orchard equipment to this practice when it is has not been planned during planting. Raising the irrigation system does not change the cost of installation if it is planned right from plantation.

   b) Mechanical weeding practices
   These are more varied in France (see Ecophyto document, Figure 16). However, there is less reference in France to the practice of mulching. This can probably be explained by a drier climate which is much less favourable to grass growth; if you want to achieve the equivalent of chemical

destruction, mulching has to be frequent. Furthermore, the manual weeding mentioned in the German document is not an option.

Finally, we should not view mechanical weeding in the strictest sense but think of it in combination with other orchard operations such as the burying of compost and prophylaxis against scab by burying leaf litter on the row. This pools costs and limits the environmental impact. A comparative analysis of the BioREco experimental network by INRA in Gotheron shows an equivalent emission of greenhouse gas, whatever weeding strategy is chosen, mechanical or chemical (the presentation brochure for BioREco is available at https://www.gis-fruits.org/Groupes-thematiques/Approche-systeme/Expe-systeme-BIORECO). Therefore, no pollution transfer from a toxicological/ecotoxicological impact to this GHG impact is observed (Fig.2 in Alaphilippe *et al.*, 2013).

c) Technical and economic context:

In France, costs vary greatly depending on the year, varieties and marketing system. The calculations carried out in the BioREco experimental system seem to be similar to the situations encountered by producers. We have observed a very weak differential between mechanical or chemical management of flora for all the reasons stated above (few passages, combination of operations). However, attention must be paid to fruit size. A smaller size is more of a penalty in France than in Germany because of different commercial standards.

In summary:

- Mechanical weeding requires an orchard that has been configured with raised irrigation.
- The mechanical weeding costs set out by the German study seem overestimated compared to practices in France.
- The suggested 'substitutive' analysis moves away from practices seeking to pool a set of practices that can be linked to weeding to benefit orchard health. In this, the situation described seems perhaps unrepresentative or requires more thought.
- The change in fruit size in situations where there is an increased presence of herbaceous vegetation is a point requiring attention and is more important in France than in Germany. Indeed, in France, the market standards are for bigger fruits.

3) What is open to debate:

a) The impact of mechanical weeding on roots: if conducted after planting, trees are not necessarily penalised (see, for example, BioREco, but this remains to be consolidated with other work). On the other hand, in an established orchard, mechanical weeding breaks many roots on the surface when first introduced (even more so with localised irrigation). The development of new options in mechanisation can mitigate this limitation. Hence, for example, Herbanet-type systems that do not work the soil.
b) The impact of weeds on crop yields and size/quality: the establishment of a grass-type cover on the row penalises size by increasing the competition for water and nitrogen (in another experiment in organic farming conducted at INRA Gotheron, one size was lost by grassing compared to mechanical weeding). There is, however, little or no data to assess the impact of some 'residual' weeds. This needs to be crossed with critical periods (for example, early spring, cold and poor soils, nitrogen availability, and water resources in the summer in the Mediterranean area) and periods when we can tolerate grass, such as the autumn. But there is a lack of objective data on these questions. And does this competition still exist when water

and nitrogen nutrition are not limited (decision support for management, implementation of ferti-irrigation)?

To conclude this comparative analysis:

- It is difficult to introduce mechanical weeding in an already established orchard: raised irrigation in all cases and damage to superficial roots even if there are alternative systems in existence which do not work the soil. This is not insurmountable but it is limiting. On the other hand, there is an advantage in integrating the possibility of mechanical weeding in the planning of any new plantation.
- It is judicious to combine several operations in one with mechanical weeding.
- There is a need for data and knowledge on the link between yield and quality and the presence of weeds in order to intervene wisely (and less frequently).
- It would certainly be interesting to work on the process of measuring 'real' costs (labour, machinery) under different scenarios. In BioREco the costs are closer to around €500 ha/yr than the €2,000 reported in the German document.
- Could the creation of a 'glyphosate-free' label during the transition period level out the differences and facilitate adoption? What about farms on which the two weeding systems will coexist in view of their current orchard configuration and how can fruit batches be separated if the same variety is produced under both 'regimes'? This is certainly worth exploring, with an analysis of the benefits and limitations.

EXEMPLE DE LEVIER : lutte mécanique

LIMITER LES HERBICIDES PAR LE DÉSHERBAGE MÉCANIQUE

L'avis du conseiller

La principale composante du coût du désherbage mécanique est le temps de travail passé, c'est-à-dire la main-d'œuvre. Des variations du coût à l'hectare peuvent être observées en fonction de l'investissement matériel réalisé au départ, du type de sol ou du positionnement des passages... Mais dans nos régions plutôt sèches, le désherbage mécanique peut concurrencer économiquement le désherbage chimique.

La substitution du désherbage chimique par le désherbage mécanique, induit une plus grande profondeur d'enracinement qui favorise la résistance à la sécheresse. La phase transitoire de cette substitution, par son effet sur l'enracinement de surface, doit être gérée avec soin. Au bout de la quatrième année, si les arbres sont bien installés, l'enherbement peut être gérer uniquement avec de la tonte et du broyage.

Le principe

Le passage d'un outil mécanique dans l'inter-rang et au pied des arbres élimine les herbes indésirables qui concurrencent et freinent la pousse et la production des arbres fruitiers.

Le désherbage mécanique améliore la structure du sol. Il favorise la vie organique des sols et la biodisponibilité d'éléments fertilisants. Les arbres assimilent mieux la matière organique.

Différents types d'outils existent.

OUTILS SANS TRAVAIL DU SOL		OUTILS AVEC TRAVAIL DU SOL en vergers de plaine de préférence, risque d'érosion en coteaux	
L'Herbanet	Brosse métallique	Décavaillonneuse à soc	L'arbocep = porte-outils
Destruction de l'enherbement présent à partir d'une série de fils montés sur un axe horizontal, qui lacèrent les plantes et nettoient le pied des arbres.	Arrache l'herbe au pied de l'arbre sur les deux premiers centimètres du sol. Elle peut être double ou changée avec d'autres outils (dents, lame interceps ou tête rotofils).	Les décavaillonneuses se composent d'un corps de charrue escamotable.	Porte outils permettant d'adapter différents types d'outils latéraux selon la nature du travail désiré (disques à chausser, disques à déchausser, lames, fraises, et mini-broyeur). Un système d'effacement (palpeur hydraulique sur la fraise) permet de s'effacer à la rencontre d'un arbre. La lame bineuse travaille à quelques centimètres de profondeur dans le sol et coupe les racines des adventices qui vont se dessécher.

Les arboriculteurs le disent

« Si je compare le coût du désherbage chimique que je faisais auparavant par rapport au désherbage mécanique c'est relativement similaire. Je vais même faire des économies à terme.
Cela me coûtait environ 4 000 €/an pour l'exploitation. J'ai acheté un outil à disque à 7 500 €, avec 40% de subvention, donc je l'aurai vite rentabilisé !
Je mets environ 1h pour désherber 1 ha en passant à 6/7 km/h. Cela permet d'incorporer la fumure organique. J'ai remarqué un meilleur enracinement des arbres. »

Figure 16: Illustration of mechanical weeding practices to control weed flora in arboriculture. Work conducted as part of Ecophyto.

3-4-3 Important points for attention

The important points for attention below are common to both fruit and vegetable production.

- Many active ingredients have been withdrawn or are in the process of being withdrawn. Around half of the active ingredients that existed in the years 1995-2000 have been withdrawn leading to some very tense situations. The profession questions whether the consideration of these 'orphan' situations is taken into account when the decision is made about which active ingredients to preserve. Similarly, some cases of resistance to active ingredients require alternation.

- Because of their direct consumption, fruit and vegetables are required to guarantee the absence of toxic or allergenic contaminants. Part of the weed flora is particularly monitored for the risks it poses to public health: quackgrass and ragweed (allergenic potential), nightshade (in blackcurrant crops and tinned vegetables too) and datura (in tinned beans).
- If alternatives are possible when plantation has already taken place, changing practices in orchards in the process of being cultivated can be very problematic. Destruction of root systems and incompatibility with irrigation choices are two frequently mentioned obstacles.
- In general, attention is drawn to the risk of the very rapid relocation of contract production (mainly for fresh vegetables for the ready to eat sector) and the loss of market share due to a decline in competitiveness in markets considered to be very fierce, particularly with Southern countries. A clear timetable should be set out for the transitional period and ensure that the application of this decision does not distort competition in its implementation within the European Union.

3-5 Overseas glyphosate use (French West Indies, French Guiana and Réunion)[4]

3.5.1 Findings on current herbicide use including glyphosate

In the French West Indies herbicide use is widespread on about 50% of agricultural land, corresponding to the area dedicated to sugar cane and banana production.

Currently 16 specialities are authorised for use on sugar cane during cultivation, none of which contains glyphosate. However, sugar cane is responsible for 30% of glyphosate use in Guadeloupe.

According to the E-Phy database, glyphosate does not appear as an authorised herbicide for sugar cane but in 55 products authorised for 'general treatments'. This covers all the operations before cultivation: clearing fallow land and the remains of the previous crop (banana and sugar cane) and treatment of field edges. In sugar cane it is even used in the inter-rows to combat the most perennial weeds. It is also used for the destruction of the plantation at the end of production. This is where the ambiguity arises because 'general treatments' can cross over into fields legally (and sometimes through misuse).

On banana, seven specialities are allowed, including glyphosate. On banana, one of the uses of glyphosate (apart from the control of grassing) concerns the chemical destruction of banana plantations before a fallow period. In particular, this use makes it possible to accelerate the elimination of telluric pests (nematodes and banana weevils). Cultivation systems incorporating this chemical destruction, soil remediation and replanting of in-vitro banana plants have drastically reduced or even avoided the use of nematicides and insecticides in banana plantations.

For other crops (arboriculture, market gardening, tubers and pineapples), glyphosate can be used before the introduction of short-cycle crops or during the cycle for perennial crops (usually under tree foliage or on the planting line). The quantities used remain limited because of the UAA involved in these diversification crops. The level of domestic use is not known but is likely to increase and is to be

[4] Notably JM Blazy, F Bussière, R Tournebize, JL Diman and L Guindé for Guadeloupe, P. Jacolot et D. Laplace for French Guiana (DAAF) and F. Le Bellec, L. De Lapeyre and Pascal Marnotte (CIRAD)

monitored. With regards to savannas (permanent meadows) these are obviously herbicide-free (30% UAA).

In French Guiana (information from DAAF), the glyphosate data recorded to supply the BNV-D database are from legal imports. In 2015, for example, herbicides accounted for 80% of the quantity of pesticides imported, of which more than 90% was glyphosate. Glyphosate volumes ranged from 5.3 to 9.8 tonnes between 2010 and 2016. However, it is known that there are also some illegal imports passing through Surinam, the largest of which are for glyphosate of Chinese origin as well as Paraquat. Little data is available describing the main uses to which farmers employ glyphosate.

In Réunion 75% of imported pesticides are herbicides (BNV-D 2014). Glyphosate and 2,4-D are the most widely used and account for two-thirds of imported herbicide volumes, with about 50 tonnes of active ingredient per year for each of them. Sugar cane cropping systems consume about 30% of this volume (before planting the crop, on field borders (in particular to control *Cynodon dactylon* (Bermuda grass)) and as a catch-up solution for some difficult to control weeds such as panic grass and quackgrass. The distribution of the remaining 70% is not precisely known but like the situation in the French West Indies, glyphosate is used in almost all other cropping systems with the same types of use (general treatments or during the crop cycle).

3.5.2 Alternatives

Research on alternatives to glyphosate use and, more generally, herbicides has been conducted as part of the rolling out of the Ecophyto plan. Some remain rather exploratory or in the form of real-life trials for various crops. References have been created and are currently available to offer a range of possibilities in each of the main agronomic preventive categories: physical, biological and chemical (see Table 7 below). In 2015, a practical guide for designing tropical cropping systems which are frugal in their pesticide use was funded by the Ecophyto plan. In addition to the proposed design method, it lists all the alternatives to herbicide use for all major tropical cropping systems. Around 50 actors from across France's overseas territories have been involved in writing it.

Table 7 – Alternatives to herbicides and glyphosate in tropical regions

Herbicide alternatives	**Reference**
General aspects and alternatives to pesticides	Guide tropical Ecophyto : Guide pratique de conception de systèmes de culture tropicaux économes en produits phytosanitaires (Ecophyto Tropical Guide: Practical guide for designing tropical cropping systems which are frugal in their pesticide use) (Buchon *et al*., 2015) https://cosaq.cirad.fr/outils-d-aide-a-la-decision/guide-tropical
	Le Guide des bonnes pratiques de désherbage de la canne à sucre (Guide to good weeding practices in sugar cane): http://cultures-tropicales.ecophytopic.fr/ct/itinéraires-et-systèmes/guides-et-manuels/les-bonnes-pratiques-de-désherbage-de-la-canne-à-sucre-
	The Wikwio portal, which presents monographs on species with weed-like behaviour: http://portal.wikwio.org/
	Martin J., Maillary L., Dutripon S., Chaulet G., Antoir J., Masson J., 2016 L'IFT herbicides canne à sucre à La Réunion : la baisse semble amorcée. 23e

	Conférence du COLUMA : Journées internationales sur la lutte contre les mauvaises herbes. 2016-12-06/2016-12-07, AFPP. Dijon (France). 11 p.
	The Caro Canne journal which includes numerous articles on weeding in sugar cane: http://www.carocanne.re/
Mechanical Physical Electrical	DAAF Guyane: Catalogue of agricultural tools[1]
	Grossard F., Grolleau O. 2016. Le désherbage mécanique en culture de canne à sucre : exemples de Guadeloupe et de Martinique. 23e Conférence du COLUMA : Journées internationales sur la lutte contre les mauvaises herbes. 2016-12-06/2016-12-07, AFPP. Dijon (France). 10 p.
Service plants	IT2 service plant catalogue: https://drive.google.com/file/d/0BxlDA5mXa72aUEtEWDJkLU14NTA/view
	Grolleau O., Grossard F., 2016. L'utilisation des plantes de service dans la culture de la canne en Guadeloupe et en Martinique : une voie qui mérite notre attention ! 23e Conférence du COLUMA : Journées internationales sur la lutte contre les mauvaises herbes. 2016-12-06/2016-12-07, AFPP. Dijon (France). 10 p.
Mulch	CIAg Guyane Octobre 2017 / R. Tournebize (online mid-November)
Spraying	Vinegar, an alternative to glyphosate – University of Maryland

[1] Editing by P. Jacolot (DAAF Guyane) for CIAg de Guyane (October 2017) based on technical and publicity videos covering a large share of the tools available (Contact P. Jacolot)

Over the course of several years, CIRAD and IT2 have developed banana cropping systems in which service plants are used to control grassing in banana systems. They explored the profiles of different species to limit grassing during the first crop cycle (strong sunshine/strong competition with weeds) and during subsequent cycles (service plants with low exposure to the sun). Innovative technologies have been developed to facilitate the establishment and management of these plant cover crops. In addition, 'typical' management itineraries have been suggested for managing weeds in banana plantations exploiting a mechanically mowed spontaneous vegetation approach (small rotary cultivator with double row planting).

For sugar cane, alternative solutions combine agronomy for good establishment through to weed control by any means. These various means are:

- Manual interventions according to the availability of labour.
- Mechanical work including inter-row hoeing, which is feasible in the first months of the crop cycle.
- The mulch offered by sugar cane as early as the second year of cultivation, provided that the straw is not removed from the field for livestock (no less than 10t of dry matter per hectare).
- Living plant barriers in the inter-row (this technique cannot be used where grass pressure is high).

- Choosing vigorous varieties during establishment, backed by conditions which guarantee good results.

Mechanical weeding by tractor (rotary spader) though with a modification to the planting scheme (change to double rows) has been worked on and refined. The technical constraints imposed by the options selected may lead to favouring double-row plantation schemes.

The diversity of weeds and situations requires appropriate adjustments and therefore needs technical support, decision support tools and training.

Biological and paper mulches have been evaluated in melon and yam crops (ongoing project). On pineapple and market gardening in general, work has been conducted on paper and plastic (biodegradable) mulching, and the use of Ramial Chipped Wood (RCW).

When mechanisation is possible, mowed permanent grassing (spontaneous or planted with service plants) is currently the most widespread technique in orchards in France's overseas departments. This management has the added benefit of providing refuge habitats for crop beneficials.

3.5.3 Economic and organisational consequences

Due to its efficacy, spectrum and low cost, glyphosate use has provided a fairly satisfactory technical solution in many important crop management stages. In the case of sugar cane, it is effective for the management of the crop from its establishment through to clearing the plot at the end of the cycle, and the management of weed competition in and around fields.

In general, reducing herbicide use requires improvements in the conditions of its use, with a more technical and professional approach (products chosen according to the flora to be controlled and the cultivation stage, adjustment of equipment etc.) and improved soil preparation conditions to increase the efficacy of pre-emergent herbicides.

In banana cultivation, there is still no effective technical alternative to replace the chemical destruction of banana plantations, which is the starting point for the fallow/in-vitro plant systems which have drastically limited the use of nematicides and insecticides to control telluric pests. This technique has resulted in rapid (around one year) and efficient soil remediation compared to previously used mechanical destruction methods.

In the absence of public support, the economic consequences are negative. In economic terms, chemical weeding is unbeatable over large areas or hard to reach areas (steep slopes) in comparison to the alternatives presented above. Currently, a herbicide treatment with glyphosate costs about €70 per hectare, excluding application costs. Nevertheless, today in banana plantations we can consider control through service plants as proven through seed imports or through the purchase of turf from nurseries. Using turf costs around €1,200 per hectare. Via self-production, it takes 1,000m^2 of nursery to grass 1 ha and production then costs about €500. These elements have been quantified in line with the certification work for MAECs (France's agro-environmental measures) for DAAF. The first results confirm that these alternatives are technically efficient but more expensive than glyphosate, with an average extra cost of about €700 per hectare per year. We should also consider the consequences of reusing some of the species used in covers in the livestock sector, particularly Desmodium. These legumes could be a source of protein and combined with banana grade-outs as a source of energy in animal feed rations.

In Guiana, mechanical and physical solutions exist, some more advanced than others. What frightens producers is the purchase cost of these alternative solutions and their mechanical reliability. This is particularly a problem in Guiana where shared purchases are rare and after-sales services are often inadequate.

In sugar cane, as in banana, the major obstacles to the introduction of alternatives have been identified and, beside the higher cost, are of three types: for manual work which is slow (stump removal), the labour cost is problematic. The other two obstacles depend on features of the particular plot: steep slopes and very stony fields. These two causes are sometimes separate, sometimes combined, and lead to a preference for chemical solutions rather than ground work. This highlights one of the effects of glyphosate: it has made the cultivation of sugar cane possible in areas in which it was initially impossible. If this impasse cannot be overcome, two questions arise: (i) what percentage of the surface area does this represent and is it likely to jeopardise the sector if this source of supply is no longer possible? (ii) Are there alternative (cash) crops that could be grown to exploit these areas and do they bring with them investment requirements for adapting these areas to this new land use (terracing, irrigation etc.)?

The organisational consequences are an increase in working time and/or a need for equipment (and inputs such as service plant seeds). Because farms are small this can be difficult without collective organisations (for example, cooperatives for sharing agricultural machinery, employer groups or new service providers) which are generally less often found in France's overseas departments.

3.5.4 Support measures

Because of the great diversity of systems and situations, the solutions presented in Ecophyto's tropical guide are interesting but insufficient for some cropping systems. A decision support tool, dedicated to both physical and mechanical alternatives, would be useful, preferably in the form of a nomadic application which monitors technology and provides updates on new methods, which are likely to become increasingly numerous as we approach the announced withdrawal of glyphosate. This type of tool is being developed by ACTA (called the CONCEPT tool), which is based on the Ecophyto guides. Support for this development would help accelerate its availability to farmers. It is also important to develop new and effective methods for the destruction of banana plantations and soil remediation during fallow periods.

MAEC (agro-environmental and climate measures) represent sustainability labels promoting crops from glyphosate-free systems and provide the framework for a ban on its use in sensitive areas (near water abstraction sites in Grande Terre and rivers in Basse Terre). Eight MAEC have been drawn up with the primary or secondary goal of reducing herbicide use: preservation of traditional Creole gardens, limiting the number of herbicide treatments in fruit and vegetable systems, no herbicide treatments in market gardens, food and fruit crops, no phytosanitary treatments in market gardening systems, replacement of the second post-emergence treatment by manual weeding in sugar cane cultivation, limiting pre-emergence chemical weed control in sugar cane, no chemical herbicide treatment in sugar cane cultivation, leaf removal in sugar cane and sustainable management of banana plantations, cancelling two herbicide treatments per year (-45%).

As part of the OPALE observatory, for more than a year chronic contaminations of surface and groundwater by various products including glyphosate and its degradation products have been recorded. At the same time, work is underway to analyse and support a group of stakeholders in the redesign of cropping systems in a watershed (work carried out as part of CIRAD's Rivage en Martinique project), which will make it possible to link practices with their effects.

3.5.5 Transversal analysis

Following this analysis, three topics immediately emerge as requiring more in-depth examination.

Apart from sugar cane cultivation, the efficacy of mulches raises the question of their production in or near fields and, of course, their removal and recycling if necessary. In addition to an MAEC, other forms of support or organisation may make sense and a cooperative or inter-sector group may want to assess its feasibility and benefits. The use of biodegradable tarpaulins, likely to boost yields following the rapid establishment of sugar cane, merits further investigation.

Living covers offer some of the advantages of covers and mulch and will also be highly complementary to mulches in maintaining biological activity on the soil surface (including beneficials and pollinators, for example). The key to choosing cover crops is finding the right compromise between their covering potential to stifle weeds and having little impact on crops. It seems important that we take stock of the list of plant species likely to fulfil this function, either alone or in combination. It is unlikely that the same solution will be suitable for all locations, so we must therefore address the issue via the biological and functional characteristics of likely cover species (including vegetation period, bearing, competition for resources etc.). Finally, some wild species may also be good candidates and this is currently being studied in citrus orchards in Réunion (Ecophyto Agrum'Aide biodiversity project).

With the withdrawal of glyphosate, 'one size fits all' solutions will probably have to give way to differentiated solutions within the field; such as hoeing, inter-row cover crops etc. It is therefore necessary to take into consideration all the consequences and requirements that the management of the maintenance of this intra-plot heterogeneity may induce.

Even if the practices are well known (false seedbeds, hoeing, mulches and service plants), they still need to be positioned in the cropping calendar under the dual constraints of the organisation of work and weed development. Many questions still remain as to the specific efficacy of these practices (for example, mulching is very effective except for liana species and *Rottboellia cochinchinensis* (itch grass)) and especially their implementation in technical itineraries, given that the biology of species which act as weeds is poorly understood.

Compared to the situation in sugar cane, glyphosate use in banana plantations therefore seems simpler, except for the destruction of plantations in which glyphosate provides subsequent savings in insecticides and nematicides. Different plant species which can be used alone or in combination make it possible to establish plant cover which is fairly easy to maintain. In sugar cane, the introduction of service plants still needs to be popularised, but their use will probably not be possible in all pedoclimatic situations and according to the weed flora present. Seeds are usually available, but supplies for large areas still need to be organised. A chain and a market need to be created, offering a new opportunity. A local organisation is emerging under the leadership of IT2 and eRcane. The two major obstacles to adoption by farmers are its technical nature and extra cost.

3-6 Orphan situations and avenues for exploration

3-6-1 Well-defined orphan situations

- The special case of direct sowing strategies for cereals under cover crops

The number of farmers implementing strict direct sowing strategies systematically across the entire farm (conservation agriculture) are few in number (around 3%) but important from a social point of view. These are highly technical farmers, socially structured and advocates for innovation, evolving their practices towards an agriculture which reconciles economic performance with certain environmental performances. In fact, the total absence of tillage, combined with an almost permanent soil cover using cover crops whose residues are returned to the ground, reduces the risk of erosion (wind and runoff), promotes microbial flora (bacteria and fungi), including the flora antagonistic to pathogens, promotes subterranean macro-fauna (earthworms, arthropods), promotes the circulation of water and reduces the problems of excess water and asphyxiation of crops in wet seasons, favours insects, some of which are beneficials, promotes crop diversity in intercrop cover crops, often with various flowering plants favourable to pollinators, and supports carbon storage. These effects seems to be related more to the high level of plant production made possible by the utilisation of sunlight throughout the year and the return of the residues of unharvested cover crops to the soil rather than the absence of tillage. However, these types of systems generally emit more GHGs. In addition, a number of these effects (for example, increased carbon storage in the soil and the increase of some organisms) are only slightly disturbed (carbon storage), or are disturbed only very transiently (macro-fauna dynamics, for example), with a rapid return to the initial state following the implementation of a tillage intervention in these systems. These systems are currently highly dependent on glyphosate, with farmers managing to avoid its use being very much the exception even among those who want to stop using it. It may even be considered that these systems only came into being because glyphosate was available.

All the farmers in the DEPHY network employing direct sowing under cover crop strategies use glyphosate, albeit often at low doses and not necessarily every year. In some years, the cover established in the intercrop period is very competitive with weeds and can be destroyed by the combination of frost and mechanical means, but these ideal conditions are rare. One DEPHY farmer using direct sowing and seeking to avoid glyphosate use, tested the technique of using superficial soil tillage using a finned toothed scalper-type tool. However, the efficacy of this tool for destroying weeds varies with the years and climatic conditions, and has not been sufficient to completely avoid glyphosate use. Furthermore, because the use of this tool disturbs the soil's structure at very shallow horizons, it disrupts sowing using the very specific seed drills required for sowing in abundant residues. Work has been conducted by ISARA to support organic farmers (therefore not allowed to use glyphosate) seeking to reduce tillage in a conservation agriculture approach. Most of these farmers have abandoned ploughing, but none of them have managed to get to a sustainable situation of direct sowing with no tillage. Finally, no direct seeding under a true cover system (i.e. without any tillage) is conducted without glyphosate in the tests conducted by INRA at its experimental sites. It is therefore clear that the current technical means do not allow farmers to persist with a strategy of direct sowing under cover if glyphosate can no longer be used. It is probably possible to further reduce doses and treat a little less often, but not to completely stop glyphosate use while maintaining the innovative direct sowing under a cover crop strategy.

The prohibition of glyphosate will inevitably result in a reintroduction of tillage, possibly very superficial but systematic, probably with a (temporary) loss of some of the environmental benefits of no-till. During an interview, the president of France's Association for the Promotion of Sustainable Agriculture (APAD) provided figures on the required traction power: while 0.9 horsepower/ha are sufficient for direct sowing practices, a range of 2 to 2.5 horsepower/ha seems the norm for those who practice Simplified Cultivation Techniques. From a social and psychological point of view, paradoxically this shift in regulations will be experienced by many of these pioneering farmers as a brutal brake on agronomic innovation and on the search for technical solutions which take into account soil ecology and agricultural sustainability. However, others will see it as an opportunity to rethink cropping systems, with a broad range of strategies based on the intensification of tillage (including direct sowing), combined with a range of other agronomic, physical, and alternative and biological chemical levers. There are some exploratory initiatives in this direction[5]. In any case, this regulatory change will have to be combined with accompanying measures to manage what will be experienced as a major transition.

- Weed management in vineyards in hillside situations without manual labour

A ban on glyphosate will call into question soil maintenance strategies, with the introduction of tillage and/or the use of plant cover as a complement or total substitution for herbicide use. However, the introduction of these techniques will be a problem in vineyards located on steep slopes, often situations found on shallow soils. This is the case, for example, of vineyards in the Banyuls region, certain sectors of the northern Côtes du Rhône (Côtes Rôtie, Condrieu and Cornas), and certain areas of the Beaujolais vineyards. Although they represent a relatively small area, these vineyards have a recognised heritage and landscape value. Steep slopes, sometimes coupled with a high planting density, have little compatibility with vineyard mechanisation for tillage or maintenance of the plant cover. These operations can often only be performed manually or using animal traction. Moreover, if mechanical work improves soil porosity, the erosion risk increases strongly in this type of vineyard when there is stormy rain. So, the total abandonment of chemical weed control currently represents a major technical impasse for this type of vineyard.

3-6-2 Research options

A question raised during this analysis relates to the relationship between glyphosate use on the one hand, and management of the weed flora as a whole on the other. We found that there was no carryover of using glyphosate to manage weeds and less herbicide use during cultivation. Similarly, we did not find the opposite relationship, where the non-use of glyphosate resulted in particular attention to weeding conducted during the growing season, including the use of authorised herbicides. Managing the withdrawal of glyphosate and managing weed flora with or without herbicides are therefore very different issues.

However, we also saw that the management of certain problematic perennials could be achieved using active ingredients approved for use in cultivation (such as the management of thistle with clopyralid, even if we know that its efficacy on rhizomes may be limited where an infestation has been established for more than a year). In addition, having an effective, easy to implement and inexpensive solution could lead to accepting certain weed levels. We do not have enough data to document the evolution of the state of weed seed banks in French soils. However, it appears in many cases that the degree of satisfaction, or even the feasibility, of this or that alternative will greatly depend on the risk of generating a situation that is difficult to manage subsequently. So, the habit of carrying out systematic preventive actions against weed flora, taken as a whole, helps to facilitate the adoption of technical itineraries which do not use glyphosate.

It is important to distinguish between research and development that can lead in the short term to solutions that farmers can quickly adopt, and research for longer-term technological innovations. Conventionally, the level of technological maturity of a technique is characterised by a scale of nine classes (Technology Readiness Level, called TRL, 1: Observation of the basic principle, 2: Formulation of the technological concept, 3: Experimental proof of concept; 4: Validation of the key functions of the concept in the laboratory 5: Technology validated in a relevant environment 6: Technology demonstrated in a relevant environment 7: System prototype demonstration in operational

[5] See, for example, Félix Noblia, Larrous farm

environment 8: System complete and qualified; 9: Actual system proven in operational environment. We have grouped different classes in order to simplify the use of TRL and adapt it to the problematic:

Class A -> TRL 9, method available on the market or proven effective through a set of examples on farms.
Class B -> TRL 7-8, validation of the method in particular experimental conditions.
Class C -> TRL 5-6, method that has proved its efficacy through experimentation and demonstrations.
Class D -> TRL 3-4, proof of concept provided. Active research/development is initiated.
Class E -> TRL 1-2, lowest level of technological maturity. Basic principles observed and reported.

Management methods for weeds and cover crops can be grouped into five major families, which will be characterised in terms of their technological maturity using these classes.

Prophylaxis to limit weed seeds in the field (P)

This first family of methods concerns only weed management. Prophylaxis involves limiting the arrival of seeds in the soil, whether that is through external contamination or through local inputs (cases where weed plants have run to seed). To achieve this, it is first necessary to limit the ratio of weed seeds present in seed at the time of sowing or planting. Seed batches sold are certified to ensure a certain level of purity of the seeds. In the case of farm-saved seed, it is useful to screen seed before use to minimise the presence of weed seeds. Cleaning tractor tyres and tillage equipment is also a way to control seed transport between plots. With regards to contamination by wind, it is possible to create hedges, and generally to manage field edges in order to limit the arrival of seed from elsewhere. When using manure inputs, it is useful to compost beforehand in order to limit the germination capacity of any weed seeds present. Finally, the management of chaff at harvest time is an effective means of limiting the number of weed seeds which fall on to the ground and is used in other countries. However, not all combine harvesters can be fitted with this option. Elements of effective prophylaxis against weed seeds have been identified but are rarely seen as priority research issues. Nevertheless, it is essential that the available knowledge is widely disseminated in the agricultural sphere, that new references fill knowledge gaps and that the associated techniques are applied.

Agronomic and genetic methods (A)

- Diversification of crop succession and genetic improvement

This lever will preferentially reduce the overall weed pressure and, to a more limited extent, those uses for which glyphosate is currently difficult to avoid. A classic way to manage weed flora is to alternate species sown in the spring and species sown in the autumn. Furthermore, since the diversification of cash crops makes it possible to extend crop successions, **it may be important to pursue objectives to improve their genetic value in relation to the expectations of farmers and markets, but also taking into account changes in management methods**. Among the genetic options, an interesting example, though probably difficult to reproduce, is that of barley. Winter barley is widely grown in cereal-dominated and autumn-crop rotations and therefore often associated with a specialisation in weed flora, particularly blackgrass, which is gradually becoming resistant to the herbicides in the sulphonylurea family. This then pushes farmers to using glyphosate in the intercrop period. The option currently being used by some cereal producers is to select varieties of spring barley, which makes it possible to have a longer intercrop period to intervene mechanically and to no longer be exposed to the same population of blackgrass, even if it shows an evolutionary adaptability towards the phenology of spring species. However, in addition to the fact that spring barley will never be as productive as winter barley, an obstacle to adopting this approach has long been the genetic level of varieties. This impasse is being broken, though, because due to its shorter life cycle, spring barley has a shortened breeding cycle (three years compared to 4.5 years for winter barley) and therefore genetic progress has been accelerated. In addition, varietal improvement work and technological progress in seed treatments on their capacity to compete with weeds during the establishment of the crop cover would support wider adoption.

- Introducing cover crops, service plants and associated crops

By increasing planned biodiversity, an increase in resilience to biotic stress is expected. In addition to the diversification of cultivated species and the alternation of sowing periods, it is also possible to increase planned biodiversity through the choice of cover crop (mono or multi-specific) during the intercrop period, by planting service plants or by associating several cultivated species in the same plot. These approaches, which fall under the banner of agroecology, lead to a higher level of complexity in agroecosystems and require sustained investigatory efforts in order to optimise them, not only in terms of weed control, but more generally in terms of the bundles of associated ecosystem services offered.

- Tillage and non-tillage under permanent cover

Tillage operations originate from the need to prepare fields for sowing. There is a wide range of operations ranging from more or less deep ploughing and turning of the soil through to more or less deep tillage which does not turn the soil. The aim of stubble cultivation is to bury the straw remaining after harvest to promote decomposition; it is also used to produce false seedbeds to initiate the germination/emergence of weeds which will be controlled before the crop is sown. The impacts of these operations are generally well known, but the interactions between these operations and other elements of the cropping system and the pedoclimate on the one hand, and the biological characteristics of the weed seeds to be managed, as well as their distribution in the soil profile, on the other, need to be better characterised in order to optimise them. In addition, advances in agricultural mechanisation could also contribute to improving the efficiency of these strategies (the ratio between the efficacy of weed control and the energy spent on doing it or the associated economic cost).

Direct sowing in plant cover is based on a strategy of minimal soil disturbance in order to provide better biological activity and favour natural regulation. Nevertheless, the impact of these systems on the biotic and abiotic functioning of agroecosystems is still insufficiently understood. Similarly, it is necessary to produce a wide range of knowledge about the effects of planting cover crops in the intercrop period in order to optimise their implementation (for example, the choice of species and varieties and the composition of associations of different plants).

The availability of glyphosate and the widespread use of this molecule may have contributed to less attention being paid to the volume and composition of the weed seed bank or the presence of vegetative reproduction organs in the soil. However, the hypothesis that there is a link between the characteristics of this seed bank and the use of herbicides in general, and glyphosate in particular, could be better supported. One can imagine that any effective reduction in this stock limits all future herbicide requirements and that it is, first and foremost, the proportion of the share of perennial weeds in this stock that will determine the ability to escape the dependence on glyphosate. Currently, we do not have the capacity to evaluate this magnitude quickly and reliably.

Subject to the validity of this hypothesis, different levers to deplete weed stocks must be mobilised. The management of the intercrop period is obviously essential, both by using false seedbeds and establishing a cover crop which will generate strong competition against spontaneous weed flora. Tillage will interact with other elements of cropping systems by causing vertical (and horizontal) movements of seeds, and by modifying the structural state of the soil horizons worked, thereby modulating the physical conditions of the germination-emergence phase (temperature, humidity and mechanical stress). For example, Figure 17 shows the density of weed seeds in three soil horizons (0-5 cm, 5-10cm and 10-15 cm), as a function of the tillage performed in maize-based cropping systems (Swanton and Shrestha, 2001; cited by Thomas, 2015). These results indicate that the seed bank is highest with ploughing. It should be noted that in this case only one third of this seed bank is a risk (0-5 cm horizon). When soil horizons are not disturbed (chisel ploughing and direct sowing), the overall seed bank is smaller, but is concentrated at the surface and so produces almost equal weed pressure. The technique of ridge cultivation, which incorporates two hoeing and earthing up interventions during the growing season, is the one that leads to the lowest weed pressure (by a factor of 3 to 4 compared to other tillage approaches). Unlike winter crops, annual grasses are the most affected by a change in practice, while the impact is almost non-existent on summer dicotyledons (Swanton and Shrestha, 2001; cited by Thomas, 2015).

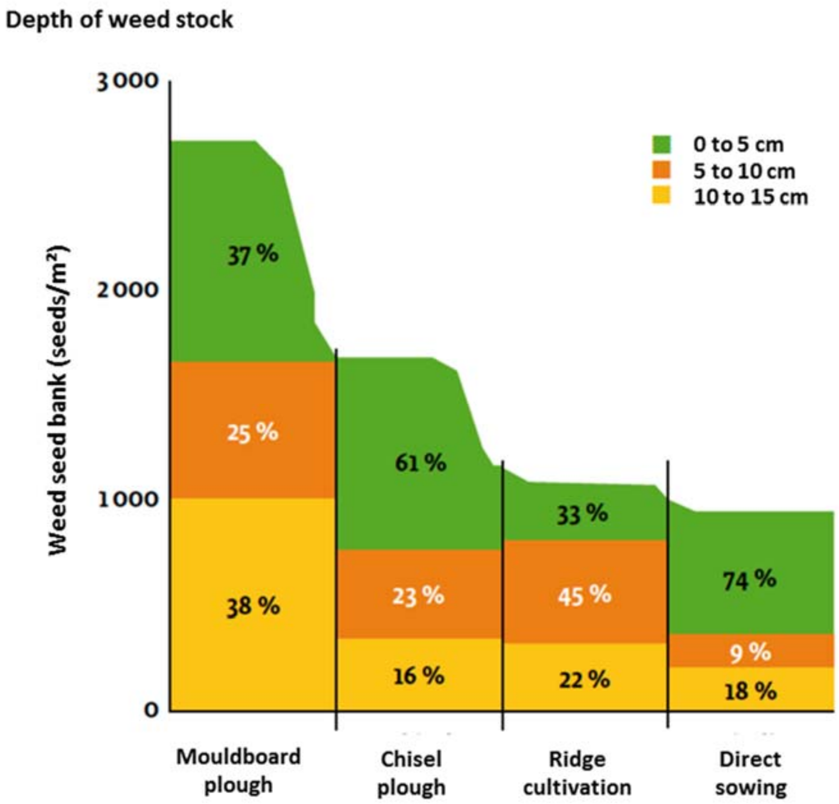


Figure 17: Weed seed distribution in soil according to type of tillage: maize crop (Canada). Swanton and Shrestha (2001), cited by Thomas F (2015).

Crop management

Each element of the cropping system is likely to have an impact on the health status of a crop. In addition to tillage, the choice of planting date and density, varietal choice, fertilisation and irrigation are all operations likely to lead to changes in the functioning of agroecosystems which can be exploited to control weed flora. The complexity of the interactions between agricultural practices, the physical, biological and chemical components of the environment and the species cultivated also require efforts to improve our understanding, especially regarding the control of weed flora. Being able to support this knowledge with management tools would be a recognised and appreciated help.

Precision agriculture

The management of spatial heterogeneities within fields is undoubtedly a point on which research and applied research should focus its work as a priority. Perennial weeds, which are the most difficult to control, are generally spread over limited areas. In addition to quantifying the costs and benefits of localised management of weeds and spatial heterogeneity, the questions raised are:

- The capacity to detect weeds in a more or less automated way, which implies recognising them (capturing images across a wide spectral range) and having the capacity to process images for rapid or immediate action.
- Localised intervention, whether that be a chemical, mechanical or even thermal intervention, or even a robot. The latter has potential and is currently the subject of technological developments (Robagri Consortium).

Physical methods (φ)

Cover crops can be destroyed by shredding or passing over the crop with rollers injuring the plants and making them more sensitive to frost damage. While specific mechanical interventions to control weeds are an alternative frequently seen in different cropping systems (for example, harrows, rotary hoes or mulch providing a physical barrier to the emergence of seedlings), thermal methods (for example, jets of steam or hot water, spreading foam or using electrodes) have only exceptionally moved beyond prototype status at the moment. The same goes for the robotisation of weeding operations, which can be effective in certain production situations, but which is still very far from being generalised. Nevertheless, physical methods for controlling weeds and cover crops are a research/development activity which is busy and being worked on by start-ups and SMEs, offering real opportunities for a green economy to support the agroecological transition.

Chemical methods (χ)

Research and development has offered a set of active ingredients to act on the physiological functioning of seedlings and weeds. Logically, their impacts on biodiversity and associated health risks have led the public authorities to tighten the criteria for obtaining marketing authorisation. The path is still open to identify new molecules or formulations that can control weeds without impacting biodiversity and without risk to human health. In the context of biocontrol, there are specialities derived from natural substances and approved to control weeds (especially based on pelargonic acid). This is a path that needs to be explored, even though the natural origin of the substances does not guarantee their ecotoxicological and toxicological safety. Some rare examples illustrate the possibility of considering the coupling of chemical and biocontrol approaches.

Biological methods

Finally, it is possible to imagine strategies which mobilise living organisms (not grazing) to control weeds, through a reduction in the seed bank and vegetative reproductive organs. Different approaches remain to be considered and combined. This includes, for example, encouraging the predation of seeds by some ground beetle species. This approach implies that seeds are on the surface and that the structure and management of the plot and the management of its surroundings (fixed elements) can accommodate significant populations of these predators. More generally, we imagine that there is also unexplored room for manoeuvre to take advantage of the ability of certain microorganisms to reduce weed seed banks by affecting their viability.

In addition, having a list of some of the most problematic weed species may open up opportunities to look for more specific beneficials.

3.6.3 The options, their level of technological maturity, their efficacy and their ease of implementation

Table 8 presents a set of techniques relating to action on flora in arable crops (weed seeds and plants and cover crops). These are characterised according to their level of technological maturity (according to the scale presented earlier), their efficacy and their ease of implementation. In this non-exhaustive list, some are already widely used while others mentioned do not constitute alternatives which can be used in the short term. In general they are not mere substitutions but should be thought of and used in combination. In addition to their technological immaturity, they will be likely to lead to other limiting effects which will need to be identified.

In most cases, we do not know the potential for improvement that putting a greater focus on these techniques could bring. When alternatives to glyphosate use seem to be unsatisfactory, it remains difficult to isolate what results from the fact that they have not yet been optimised and what are intrinsic qualities which will always be difficult to work around. The cost of equipment is an obstacle considered rather transient because it can be the subject of support measures. On the other hand, slow work rates or the material inability to deploy equipment in certain areas, such as some types of tillage in soils which are far too stony, represent a technical impasse.

Bearing in mind these precautions about what this compilation means and does not mean, the major options fall into a typology that combines preventive measures (including intercropping and associated crops and lengthening rotations), then chemical curative measures, physical measures (in several forms according to the target stage: tarpaulins, mowing, tillage) and biological (biocontrol but mainly cover crops). Sometimes synergies can be exploited by coupling mechanical and chemical measures and biological and chemical measures (essentially grassing) which can help to reduce the doses used. In presenting this section on the alternative avenues to be explored in order to make progress, we do not want to suggest that the avenues are numerous, ready and that they will succeed in the short term. It is the role of research and applied research to explore avenues, some of which will not ultimately succeed. At the same time, that’s where we see the best opportunities.

	MATURITY	FEASIBILITY	EFFICACY										
			Broadleaf perennials	Grass perennials	Broadleaf intercrops	Grass intercrops	Directly sown broadleaf intercrops	Directly sown grass intercrops	Plant cover intercrops	Directly sown plant cover intercrops	Directly sown permanent cover	Destruction of pasture	Regulation of cover (fallow)
Glyphosate (χ)			*	*	*	*	*	*	*	*	*	*	*
New herbicides (χ)			*	*	*1		*1		*	*	*		*
Natural substances ($χ_b$)					*2	*2	*2	*2	*2	*2			*2
Seed purity (P)			**	**	**	**	**	**			**		
Cleaning equipment (P)			**	**	**	**	**	**			**		
Chaff management (P)			**	**	**	**3	**	**3			**		
Edges/hedges (P)					**4	**4	**4	**4			**4		
Composting (P)			**	**	**	**	**	**			**		
Rotation/species (A)			**	**	**	**	**	**			**		
Varietal choice (A)			5	5	5	5	5	5	5	5	5	5	5
Sowing date (A)					*6	*6	*6	*6			*6		
Sowing density (A)					*	*	*	*			*		
Fertilisation (A)			5	5	5	5	5	5	5	5	5	5	5
Ploughing (A)			*	*	*	*			*			*	
False seedbeds (A)			*	*	*	*			*			*	
Rolling and frost (φ)									*7	*7			
Shredding (φ)									*	*	*	*	*
Robots (φ)													

Table 8: Analysis of the potential of different methods to control weeds and cover crops in arable production.

Each method is characterised by its level of technological maturity (M), ease of implementation (F) and efficacy (E). The following colour codes are used for each of the three criteria. Level of technological maturity: dark green: already marketed and/or used; light green: demonstrated its efficacy in many cases; orange: method validated under particular experimental conditions; yellow: proof of concept provided, active research phase; red: lowest level, only basic principles are formalised. Feasibility and efficiency: dark green: very high; light green: high; orange: average; yellow: poor; red: very poor. The colour codes of cells divided in two indicate the extremes of the variability of the criterion concerned. In grey: not applicable.

Meaning of remarks numbered from 1 to 7 (Source ITA). 1. Only the combination of several active ingredients would make it possible to find a broad spectrum (though still limited than that of glyphosate), 2. Economic constraints (> 300 €/ha) and logistical (12 to 16 l/ha), 3. Does not work on blackgrass, 4. Only works on certain flora; including, cleavers, bromegrass, milk thistle and ragweed, 5. Lever suitable for herbicide reduction, 6. Easier to do and more effective in spring crop. Strong constraint before cereals. Impossible in oilseed rape, 7. According to the availability of the number of frost days; effective in northeast France.

: effect in year n, directly on the crop regardless of infestation level;* *: long-term effect or contribution to maintaining limited seed bank.*

4 Accompanying measures - Glyphosate transition

4.1 Summary of difficult situations requiring special attention

Here we offer a gradation of the ease (or not) of ending glyphosate use. ‘Evolutionary’ signifies it is easy to avoid glyphosate use, ‘major’ signifies alternatives which pose more or less generalised difficulties, and ‘impasse’ is used for those situations where we perceive that there is no way to compensate for the removal of glyphosate other than through the use of labour to carry out manual intervention in the fields.

Through our reading, interviews and exchanges, we have identified some major transition situations that are particularly difficult, even impasses, of which the following table presents a summary. The ITAs (France’s agricultural technical institutes) have produced a summary, breaking down these situations and targets. This document, the spirit and conclusions of which we share, is provided in Appendix D.

Table 9 - Summary of situations and gradation of level of difficulty.

Situation(s) concerned	Character of obstacle	Alternative(s)	Area (hectares)	Volume of glyphosate (approx. tonne)	Need induced	Probable consequences
Harvesting of nuts (Hazelnut)	Evolutionary (harvest management)	Harvesting on a cover previously mowed flush or on tarpaulins	4 10^{+3} ha	10	Other harvesting equipment (without the bare soil sweeping step), cover for this purpose	
Conservation agriculture with direct sowing (under cover) with no tillage	Impasse in principle (don’t touch the soil)	Almost none without changing the system; combining adapted cover and techniques for destruction/close shredding	4% of 15 10^{+6}, or 600 10^{+3}	4% of arable (1,600 t) or around 64 t	Frost-sensitive cover, good destruction through rolling, characterisation of heterogeneities for isolated one-off action, intervention with scalper	Majority return to SCT techniques, evolution of cover management methods
Certified seed production chain	Major (management of impurities, cultivated species which are uncompetitive such as vegetables)	Agronomical practices for field preparation before sowing, other herbicides	(of which 24 10^{+3} for lucerne)	> 8	Characterisation of heterogeneities, densimetric and optical sorter on packing line; development of alternative management itineraries (FNAMS)	Delocalisation for major groups

Vine management on steep slopes and very stony soils	Occasional impasse, if not then major	Manual action, draft animals?	Beaujolais, vineyards in Banyuls, Maury, Côtes Rotie, Condrieu, or $3\ 10^{+3}$ ha env.	>6	Alternative herbicides, adapted tillage	
Flax retting	Major (finding the right compromise to leave flax on the ground without risking of it being covered)	No substitution; upstream work on the risk of weed emergence during the critical period	70% of flax area			Reduced ability to capitalise on world-leading know-how
Absence of impurities in field-grown ready to eat fresh vegetables (lettuce, lamb's lettuce)	Major (in the specifications of the sector covering this market)	No substitution; work on seed bank, preparation of seedbed, sorting on packing line		< 1 tonne	Occasional, thermal weeding; robotisation; biocontrol targeted at toxic weed species	Distortion of competition, imports, concentration of the sector if dissuasive robotisation costs
Management of intercrop cover	Evolutionary (economic and sometimes reversible)	Mechanical weeding extended beyond current vulnerable areas; adaptations of technical itinerary	$15\ 10^{+6}$		Precision agriculture for more localised actions in the field, development of characterisation of environment for adjustment of interventions, generalisation of intercrop covers, differentiated management on and between rows (weeding, passage in rooted crops)	Incompatibilities between directives (nitrates), need for integration into pillars of CAP, market losses, growing consumption of fossil energy, increased costs (including labour)

Orchards in production with neither good spacing nor suitable irrigation	Evolutionary (upstream rethink of modification to planting)	Mechanical weeding	Ranging between 10 to 20% of orchards	15% of 20 10^{+3}, or 3 10^{+3}	Mowing system, elevated irrigation system (buried?), tillage on the row, coupling interventions, adapted cover, mulching, heterogeneity management and differentiation on and between rows	Competition of non-controlled grass cover in orchard results in a loss of size, more of a penalty in France than other EU countries
Sugar cane crops (overseas)	Evolutionary, occasionally an impasse (on risky or difficult soils)	Other herbicides, mechanical weeding, devitalising by mechanical grinding				Rotations to be rethought in some areas; appearance of fraudulent pesticides?
Absence of toxic contaminants in orchards producing small fruits	Evolutionary	Mulching, prophylactic agronomy			Development of biocontrol solutions, strengthening of packing chains, increase in labour	
All	Major (major trends of the past 30 years)	Consistency of systems, production tools, chains and markets, investments on the farm, the moral burden of more significant decision-making			Polyculture-livestock, diversification of rotations	Labour costs, penalties and lack of outlets, reorganisation of collection chains; maybe processing

<u>The irreversibility of the paths taken</u>

Since its introduction in 1974, glyphosate has gradually become a cheap, easy to use and effective product. Its popularity has led to widespread use and questioning this use highlights the degree of lock-in for some sectors which use it extensively. Conservation agriculture is a good example of this situation. Farm structures (increase in size combined with a reduction in labour units) as well as the range of agricultural equipment related to the adoption of other approaches to tillage, are two concrete translations of the changes which have taken place over recent decades.

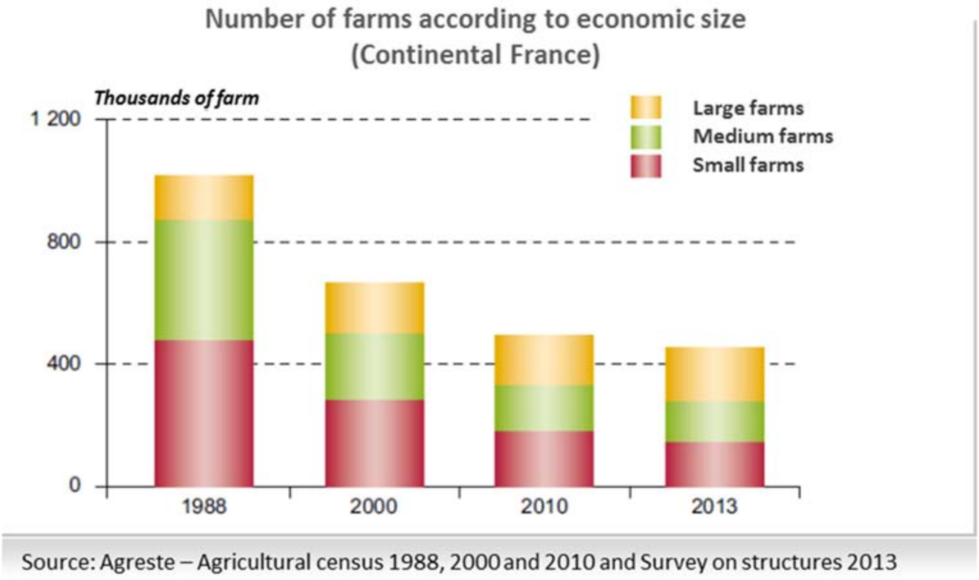


Figure 16: Changes in farm numbers and their distribution by size. Source Le Monde (7/11/2014).

This change has been supported by an increase in work flows, boosted by mechanisation and pesticide use. These productivity gains have also been accompanied by an increased ability to overcome spatial heterogeneities within fields by masking them.

Some farms have been able to manage weeds and crops in the intercrop period without glyphosate. However, a change in the regulatory context, combined with the limits observed through the analysis of the DEPHY data, underlines the transient or profound destabilisation that a withdrawal of glyphosate will create. It is a destabilisation that will have to be alleviated through support measures. The measures which follow take this transition into account and include the economic, technical and pedagogical efforts that will have to be coordinated.

4-2 Economic and financial risk reduction instruments

4-2-1 Investment support

As the coherence of public policies is particularly important, a preamble specifying two paradoxes seems to us to be necessary.

The perspective of a total ban marks a rupture with the logic of simply reducing the use of plant protection products. It is therefore natural to want to revisit the incentive measures based on this decisive difference whenever the objective of optimisation and reduction does not fit into a logic compatible with a total ban. Nevertheless, there is a risk of losing whole areas of interesting R&D, especially for the transition period and especially as these innovations could be of generic interest for pesticides more globally.

So, setting aside the overall coherence of actions to reduce the use of plant protection products and focusing on glyphosate, we can see that there may be medium/long-term impacts that may not be predictable and desirable, even including the increased use of other herbicides or other pesticides (banana plantations are a case in point). For example, it appears that the rational use of glyphosate could be a lever to greatly reduce the soil seed bank and ultimately reduce its use. This may seem counter-intuitive compared to the average usage range we currently observe, yet this potential, already well understood and managed by a small fraction of farmers, could be implemented during the transition period.

Perennial weed flora is the most difficult to manage and is the situation in which replacing glyphosate will be most difficult. In general these perennials are distributed very heterogeneously across agricultural fields. Glyphosate's mode of action of makes it possible to destroy the underground organs which are often elements of the vegetative multiplication of these species. The consideration of spatial heterogeneities involves being able to move from a generalised application to a localised intervention and so must integrate:

- The characterisation of this heterogeneity and automatic weed recognition, maybe simultaneous recognition of disease outbreaks for overall savings in the use of plant protection products.
- Robotics, automatism and drones.
- Modelling the inter-annual propagation of heterogeneities.
- The establishment of chains and associated services for mulching.

On the other hand, a ban on glyphosate leads to distinguishing between the equipment associated with redesign strategies and that associated with 'substitution' strategies (replacing chemical weeding with mechanical weeding) and 'improving efficacy' strategies (optimised spraying). Optimisations are limited to reducing the quantities of active ingredient used without seeking to redesign cropping systems to completely escape herbicide use. The investment categories making it possible to construct systems which are less dependent on glyphosate and herbicides in general are currently not included in the lists of agro-environmental investments eligible for public support (Ecophyto 2 in particular). These should be created in order to be able to target aid and encourage this type of investment.

According to the conclusions of this study, it is important to highlight actions that promote:

- Diversification of planned biodiversity (crop species, intercrop cover, service plants, seed sorters and separators for mixed crops, for example).
- The rapid establishment of crops (species and varieties with strong plant vigour).
- Prophylactic actions which step-by-step limit contamination.
- Limiting seed banks in the field (machinery, chaff management etc.).
- The differentiation of weeding in the plot (on or between rows, spot by spot, vine stock and fruit trees).
- Mechanical weeding of crops.
- Mulching.
- Work flows for preventive actions (preparation of seedbeds and sowing itself) and remedial actions (mechanical weeding with finned-tine scalpers, weeding robots in viticulture etc.).
- The creation of specific chains for weeding services (support for the use of animals for the management of difficult flora in cereal fields, support for collective management initiatives for herds.)
- Research/development on technological innovations (automation, and thermal, chemical and biological levers).

As a result, during the transition period, investment aid (PCAE (investment support), Ecophyto 2 etc.) would be allocated as a priority to farms that do not use glyphosate. The lists of actions eligible for this aid would be augmented by agricultural equipment enabling glyphosate use to be avoided.

4-2-2 Mobilising MAEC systems

The removal of glyphosate is already taken into account in MAEC systems (France's agro-environmental and climate measures), since some of them include a reduction of TFI. In the context of the withdrawal of glyphosate, these MAECs must be supported even if they do not specifically target this molecule. In the longer term, and with a view to an increased reduction in the dependence on plant protection products, it would be feasible to develop MAEC systems which incorporate a TFI reduction of at least 30% and practices (rotations, for example) to reduce weed pressure on crops (SPE - livestock, SPE - crops, SPE - monogastric animals, SGC (arable systems)).

This idea is supported by the fact that the MAEC systems already mention many techniques which are favourable for the withdrawal of glyphosate:

- Promoting crop diversification
- Alternating sowing periods of crops in the rotation
- Delaying autumn planting
- Combining stubble cultivation with tooth and disc tools
- Better positioning of stubble cultivation
- Improving the depth of tillage during stubble cultivation

In order to improve the performance of the MAECs, measures could be added that will favour crops with a high cover density, notably through the association of species. If there is no prior infestation with perennials, intercrop covers, introduced as a requirement in the Nitrates Directive, may be chosen to provide an overall reduction in weed flora, including perennials, by limiting fresh supplies to the soil's weed seed bank.

Consequently, MAECs should be extended to promote the management of intermediate crops, which are a major lever that can be used to influence weed flora: choosing the nature of the species to be planted and improving their management (early sowing, density and destruction methods in particular). This extension should be accompanied by an authorisation not to plant an intermediate crop in cases of proven strong weed infestation, including perennials, but to replace it with a period of appropriate repeated tillage to germinate seeds, exhaust the seed bank and drastically reduce infestations.

4-3 Mobilising experience sharing, advice and training

Beyond the means that farmers will have to put into effect, our study has shown that technical itineraries and the succession of crops will also have to change. In addition, practices will have a greater focus on the peculiarities of each plot.

The advice provided to farmers is changing and will move towards:

- Support for the design of new cropping systems and in particular for the issue of glyphosate, the choice and management of intermediate crops and the positioning of tillage and cover crop maintenance.
- Support for moving towards a multi-year strategic and tactical reflection.
- The appropriation and implementation of technical interventions to reduce the seed bank, while reducing herbicide use.
- Raising awareness of non-chemical alternatives and education to teach actions which are more technical and potentially more difficult to implement.

- More broadly, the coordination of farmers' collectives for agroecology with low pesticide levels (France's plan to support 30,000 farms nationally). In this context, it may be appropriate to introduce a 'zero glyphosate' criterion in the next screening of candidates for collective action in the 30,000 plan (strict eco-conditionality).
- Advisors will identify non-glyphosate farmers who can share their experiences.
- The provision to all (farmers and advisers), through the GECO tool for supporting reduced pesticide use, of effective alternative techniques and the successful experiments of farmers who do not use glyphosate. These actions will also be translated into CEPP (pesticide savings certificates) action sheets.

It will also be necessary to translate the change that is taking place in the guidelines for initial training in agricultural education, which have recently been revisited as part of the 'Teaching to produce differently' plan.

Consequently, the dynamics of experience sharing between farmers and advisers in the field should be supported and enriched. The exchanges between Ecophyto 2 (30,000 plan and CEPP) and all farmers should be increased.

4-4 Regulatory levers

Regulations are a cornerstone of any innovation and transitional approach and the withdrawal of a molecule or marketing authorisation is part of this regulatory set.

The different options concern the encouragement for a transition, a search for consistency between public policies to avoid paradoxical injunctions and, finally, the maintenance of chemical solutions for emergency situations.

- Modulating the CEPP (certificates to encourage reduced pesticide use), by reinforcing the value of the action sheets contributing to the disappearance of glyphosate use.
- Mobilising information from the DEPHY networks to change regulations for farming without glyphosate use.
- Adapting specifications and market standards to promote the emergence of chains and labels officially recognising 'no glyphosate' production during the transition phase.
- Coherence of public policies
    - The prohibition on summer tillage in some areas does not allow farmers to pass over fields with tools equipped with discs and teeth, whose action on weeds is very effective in hot, dry periods.
    - A total ban on glyphosate could lead to postponements in R&D and reduce other work aimed at pesticides or an overall reduction in the use of plant protection products.
- The coherence between countries and the risk of distorted competition by limiting and tracing imports of products that have 'benefited' from glyphosate applications.
- With a view to full application, and eventually localised, the maintenance in the pharmacopoeia of molecules of those active ingredients which can control perennial weeds, managed until now by glyphosate. These molecules are identified in Annex C of the document where their hazard spectrum is also specified.

4-5 Strengthening collective organisation

Organisational innovations are important levers to support the transition to glyphosate withdrawal.

- Promoting joint work and investments between farms. We have identified:

- Sorting equipment for farm-saved seed.
- Stubble management, other than destroying it by burning.

- Encouraging the development of an offer from agricultural contractors using new equipment for differentiated management of weed flora within the field.
- Establishing partnership approaches between research and applied research to explore and offer specific innovations on specific topics such as the withdrawal of glyphosate.

4-6 Research and applied research: methods and priorities

The analysis of the whole field of possibilities for avoiding glyphosate use has revealed knowledge gaps and the need for innovations.

The DEPHY experimental networks must be mobilised, especially when the new generation of experimentation is introduced. The goal is to identify and promote those systems and practices that help reduce weed pressure without the use of glyphosate or other alternative herbicides (many networks already do this). On another note, as part of the work of Ecophyto's Scientific Committee for Research Orientation and Innovation, it will necessary to guide the call for tenders. This can also mobilise the Casdar calls for projects and, in particular, those concerning 'Technological Research' and 'Innovation and Partnership'.

Among the priority themes, we have identified:

- Redesigning systems which are less dependent on herbicides and, in the longer term, on pesticides in general, including the use of seed treatments.
- Strengthening research on intercropping to produce high biomass cover crops which are highly competitive and easy to destroy: choice of species and varieties, sowing density.
- Robotics and automation for the increased use of mechanical weeding and for the control of spatial heterogeneities and, more widely, research on mechanical weeding. *Organisation of meetings between teams to define standards for the quality of mechanical weeding and the management of intra-plot heterogeneities*.
- Producing a set of CEPP action sheets dedicated to the reduction of glyphosate use.
- *Ex ante* and *ex post* analyses of the socio-economic and organisational impacts of the withdrawal of glyphosate. This point is particularly important because the economic analysis is difficult but decisive in farmers' decision making.
- Developing decision support tools dedicated to a risk-free escape from glyphosate dependence with no after-effects.
- Analysis of historical land use to extend or rationalise the switch to other crops that are compatible with glyphosate-free production (areas with high erosion risk, slopes, very stony soils etc.).
- A programme focused on biocontrol of perennial or problem species, and on the alteration of the seed bank, including vegetative propagation organs. *Organisation of meetings between teams to define standards for the quantification of soil seed banks.*

5 Conclusion

When reflecting on the withdrawal of glyphosate it is obviously important to contextualise this in the overall trajectory of reducing the use and impact of all plant protection products, including herbicides, which is embodied in France by the Ecophyto plan, the national variant of European Directive

2009/128. And yet, compared to this general trajectory, glyphosate occupies a very particular place because it cannot simply be replaced by other herbicides as it is used either to solve specific grassing situations or for the simple management of all weed flora.

Indeed, if we analyse it only economically and agronomically, glyphosate combines many strengths which can be summarised as a broad range of efficacy combined with low cost and ease of use. Now subject to controversy, its environmental impact profile was considered rather favourable during the various pre-market assessments. These strengths have been brought to bear in many situations, for example, glyphosate made it possible to intervene in difficult terrain, has been used as a substitute for hard manual labour, made it possible to devitalise perennial weeds and crops at the end of the growing cycle, and replaced mechanical work to ensure good weeding. Since its introduction in 1974, glyphosate has gradually conquered these new uses, sometimes replacing molecules whose market authorisation had been removed. Undeniably, glyphosate has been able to support the development of a large share of agriculture. France, like other countries, has never taken the step of cultivating GMO varieties which are tolerant to its use. But for other uses, it has allowed some farmers to extend their farms through improved work rates, others have been able to stop ploughing and change the agricultural equipment required accordingly, others have introduced its use to plant crops on land hitherto unsuitable for cultivation and others in order to harvest in better conditions. There are so many situations that nowadays will face varying degrees of difficulty or impasses. We knew how to conduct agriculture before and we will know how to do it ‘after’, but the changes in structure and organisation experienced by French (and European) agriculture in recent decades, some of which were made possible precisely because of glyphosate use, mean that we cannot consider a return to ‘before’ but are obliged to build a different ‘after’.

Technical alternatives must be able to maintain pressure on weeds, ensure the destruction of cover before crops are sown, maintain vines and orchards, and facilitate harvesting in good conditions. If glyphosate is withdrawn, farmers will need to introduce the following alternatives alone or in combination in order to maintain their income and yield levels:

- Physical destruction through mechanical weeding and surface tillage, particularly during the intercrop period for annual crops, or at the foot of vines and trees in viticulture and arboriculture. This also includes the use of tarpaulins or ground cover with straw.
- Ploughing to ensure the destruction by burial of all vegetation. This also buries weed seeds on the soil surface, which prevents their emergence during the following season, though limits their predation by insects.
- A sum of partial avoidance strategies including the use of winter freezing of intermediate covers, through the choice of adapted species, or the use of specific agricultural equipment allowing vegetation to be ground. This avoids the need for total chemical destruction.
- Cropping under living mulches, a tactic which induces a major modification in weed flora and limits perennial or problematic weeds.
- The targeted use of other registered herbicides (which may have more adverse toxicological/ecotoxicological profiles than glyphosate) may be required during a transition period to treat perennial weeds that would withstand the previous options.

The difficulties or impasses identified as the most serious relate to work flows linked to the extension in farm sizes (associated with irreversible and profound demographic changes in the countryside), the evolution in no-till conservation agriculture systems (due to changes in equipment and motorisation as well as the major principle), changes in rotation, especially in difficult situations such as easily waterlogged soil, stony ground, sloping plots or plots at risk of erosion (in line with increased territorial specialisation), crops for specific markets with strong technical constraints (seed production, fresh and canned vegetables grown in open fields) and finally the choice of production and tools that require a vegetation-free surface or free land for sweeping and vacuuming the harvest (because of path dependency in the construction of agricultural equipment). The more general obstacles concern the economic balance, especially during the transition, before the alternatives have been adapted and they have benefited from a fall in their cost as a result of their increased use.

The support measures recommended concern investment aid, the mobilisation of the MAEC systems, mobilising the collective dynamics in agriculture and advice and training, the use of regulations and in particular CEPP, and the organisation of chains, in particular by promoting the recognition of products from glyphosate-free sectors. Research and applied research will also play a role, both for the control of intra-plot heterogeneities and the creation of new options via, for example, biocontrol.

Clearly, without a vision of the transition time, without knowing the margins for improvement in the different alternatives, without a clear understanding of the degree to which extra costs can be recuperated in prices and the willingness to pay for end products, and without knowing what our neighbours will do, it is tempting to stress the real and supposed impasses and to favour the status quo. In fact, since other paths have been taken, it is not easy to know if it is possible to collect hazelnuts by suction on a closely mowed cover or if other crops are possible on land which is considered difficult, if enough mulch will be available to cover those situations which will require it and, especially, if the lack of supply in certain sectors or collection points due to changes in rotations will induce a domino effect with varying levels of impact.

To avoid being prisoners to these forecasting difficulties, our starting point has been real situations. We are aware that the situations identified can result from different histories and long-term trajectories. We also acknowledge that the existence of a situation B not using glyphosate with very many similarities to a situation A, which uses glyphosate, says little about the time and path required to go from A to B. We have not seen any major needs for adjustments in equipment or engine power (with the exceptions of farmers who direct sow and want to switch to simplified cultivation techniques with the removal of glyphosate, and large-scale farms where work flows have become a structuring element). Similarly, while we have noted logical changes to schedules, with more tillage interventions approaching sowing, these changes appear to be of a moderate magnitude and are often shifts rather than additional interventions (with the exception of the mechanical destruction of the intercrop cover if this intervention is to take place at a specific time). On the other hand, we have no indicators of the state of soil weed seed banks, which can mean the difference between situations that will require major efforts to contain weeds and others where it will be relatively easy. Knowledge on weed seed banks therefore seems a key factor, but is so far very difficult to access. Nor do we have any measure of the mental burden that may result from the need for smarter observation-based practices to be conducted over longer time periods, sometimes with the help of employed personnel, even though the number of favourable days for mechanical interventions may be fewer; in short, we cannot account for the relative tranquillity that could be engendered by ease of use combined with the relative certainty of the result.

The analysis of the various situations underlines the fact that ending glyphosate use will not be achieved by the use of a single option for all, or even of a unique technical option for a given farm or cropping system. Therefore our recommendations are steered towards the identification of locally adapted technical combinations. This contributes to the apparent complexity and mental burden, especially during the transition phase.

The analysis of real-world datasets and of the scientific and technical literature highlights solutions that are of different technological maturity levels, from technical options already available through to options requiring further development and some even requiring proof of concept. Research and applied research should be pursued on the issue of withdrawing glyphosate and, more broadly, on reducing the use and impact of plant protection products. But the study conducted here introduces a break in paradigm which should be further investigated. The glyphosate situation and situations of potential impasses prompt reflection on another way of using pesticides in general and herbicides in particular. Indeed, the use of this molecule will be most difficult to replace in its role against perennial weeds and the underground vegetative fragments which allow them to propagate. In many cases, however, these weeds only cover a small proportion of agricultural plots and the new challenge is therefore to clearly take into account spatial heterogeneities, their characterisation and their inclusion in crop intervention and protection programmes. This requirement has not been sufficiently shared with the field of precision agriculture and therefore requires more work.

This report does not deal with the regulatory dimensions and public decision making, but with the issue of transition. While in many ways glyphosate use embodies a technological lock-in situation around a molecule, the transition's initiation and progress will require genuine clarity and stability in public decision making and regulation.

Finally, throughout this report and while recognising the differences, the authors have sought not to isolate glyphosate from the whole question of pesticide reduction. Indeed, it would be wrong to believe that the search for a path to reduce pesticide use and risk can only be achieved through the analysis of the effects of the removal of molecules taken separately, even if they are used so massively in terms of both their tonnage and their Number of Dose Units (NODU) as glyphosate. In fact, the availability of glyphosate has made it possible to resolve the difficulties created by poorly thought-out protection programmes at other stages in the cropping cycle, such as the development of grass weed flora resistant to sulphonylurea. Conversely, the withdrawal of glyphosate is likely to lead to uses, in more limited volumes, of molecules with less favourable toxicological profiles to control the most difficult flora, even other pests if we consider the management of banana plantations. It is therefore crop protection in its entirety that must be and remain the priority, favouring the redesign of efficient systems and with regulatory frameworks which encourage the design and implementation of virtuous actions, while retaining the ability to adapt to local conditions.

In terms of analytical resources, the work conducted for this request has demonstrated the power of calculation and analysis offered by the DEPHY farm network, both in its breadth (diversity of situations described, accuracy of information on cropping systems) and its depth (tracking over time of farm trajectories). This information system is a vital resource for the transition of French agriculture towards systems that are more parsimonious in their use of plant protection products.

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7 - List of experts met or associated with the study and their organisations

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8 - Annexes

Annexe A Request for study

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE

MINISTÈRE DES SOLIDARITÉS ET DE LA SANTÉ

MINISTÈRE DE L'AGRICULTURE ET DE L'ALIMENTATION

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR, DE LA RECHERCHE ET DE L'INNOVATION

Les Ministres

à

Monsieur le Président Directeur Général de l'INRA

Paris, le 02 NOV. 2017

N/Réf :TR507024

Objet : Saisine sur les mesures alternatives à l'utilisation du glyphosate.

L'approbation européenne du glyphosate expire le 15 décembre 2017 et les discussions sont en cours sur la proposition de la Commission européenne. Celle-ci a proposé de renouveler l'approbation pour une période de 10 ans, assortie notamment de cette condition pour les Etats membres :

« *porter une attention particulière aux aspects suivants lors de l'évaluation des produits contenant du glyphosate, en adoptant les mesures appropriées de réduction du risque :*
- la protection des eaux souterraines dans les zones vulnérables, en particulier pour les usages non agricoles ;
- la protection des opérateurs ;
- les risques pour les vertébrés terrestres et les plantes terrestres non ciblées ;
- la conformité des utilisations en pré-récolte avec les bonnes pratiques agricoles ».

Les autorités françaises ont indiqué que cette période de 10 ans était trop longue compte tenu des incertitudes qui subsistent sur la substance.

... / ...

78 rue de Varenne – 75349 PARIS 07 SP - Tél : 01 49 55 49 55

Le 25 septembre dernier, le Premier ministre a annoncé que la France définira d'ici la fin de l'année les conditions d'un plan de sortie du glyphosate, compte tenu de l'état de la recherche et des alternatives disponibles pour les agriculteurs et en fonction des conclusions des Etats généraux de l'alimentation.

Afin de préparer cette échéance, il est demandé à l'INRA de procéder aux études suivantes, en lien avec l'IRSTEA, les instituts techniques de l'ACTA et les autres sources d'expertise pertinentes (dont la Commission d'Evaluation indépendante des CEPP du plan Ecophyto) :

- identifier les principaux usages agricoles du glyphosate, y compris leur évolution au cours des dernières années à partir des données transmises par les pouvoirs publics ;

- préciser, pour chacun d'entre eux, les alternatives possibles, notamment mécaniques ou biologiques, en tenant compte de l'ensemble des projets de recherche et de recherche appliquée (Ecophyto et al) ;

- estimer pour les alternatives identifiées les conditions nécessaires et les modalités de cette mise en œuvre, y compris les adaptations requises et l'évolution induite des pratiques au niveau des exploitations agricoles et des filières. Vous examinerez tout particulièrement comment favoriser les alternatives évitant la substitution par d'autres produits phytopharmaceutiques. Vous pourrez, lorsque les données sont disponibles, évaluer les impacts économiques et environnementaux de ces alternatives.

Pour le cas particulier des outre-mer, l'étude devra s'appuyer sur l'expertise du Réseau innovation et transfert agricole (RITA) coordonné par le CIRAD et l'ACTA.

En complément de ces éléments, vous proposerez des mesures d'accompagnement des exploitations agricoles et des filières (aides à l'investissement, formation, conseil...), pour chacun des usages et de ses alternatives identifiées, qui pourraient contribuer à faciliter la transition vers la non-utilisation du glyphosate, en tenant compte des programmes existants pour la réduction de l'usage des produits phytopharmaceutiques.

Vous proposerez également les besoins en recherche et développement qui permettraient de développer de nouvelles alternatives à moyen terme.

.../...

Vous veillerez à prendre l'attache de la mission conjointe CGAAER-CGEDD-IGAS sur les produits phytosanitaires, afin d'assurer la bonne articulation et complémentarité de vos travaux.

Vous nous rendrez vos conclusions au plus tard pour le 30 novembre,

Nicolas HULOT

Agnès BUZYN

Stéphane TRAVERT

Frédérique VIDAL

Annexe B Charting glyphosate use in France by crop ranked in broad categories

Point in direct connection with solicitation No.1 of the referral and before the presentation of our typology extracted from DEPHY. *'Identify the main agricultural uses of glyphosate from data provided by the public authorities and comment on the developments observed in recent years.'*

Work based on the SSP-Agreste surveys. Data was extracted directly by the Ministry's Department of Statistics and Foresight.

Different crops have been surveyed in different years.

Species	Year (cropping season)	
Arable crops	2011	2014
Vegetables	2013	
Arboriculture	2012	2015
Viticulture	2010	2013

Given the extrapolated values of the region * crop cross, the recommendation on the validity of these results is limited to 3 points:

- Average input per crop
- Broad outline of distribution of glyphosate between crops
- Relative average share of glyphosate in herbicide treatments per crop

Series of summary tables arranged according to the decreasing average consumption of glyphosate.

N.B.: The convention is that management of the intercrop is attributed to the following crop.

Arable crops

Species	Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
Sunflower	All - 2011	179 663 953	263,0	226 814	0,33	1 331 531	1,95	13,3
Protein pea	All - 2011	25 496 634	159,9	34 428	0,22	447 950	2,81	6,4
Grain maize	All - 2011	194 529 247	132,2	220 001	0,15	4 249 282	2,89	4,3
Barley	All - 2011	166 848 573	126,3	244 543	0,19	2 654 889	2,01	6,3
Forage maize	All - 2011	132 203 078	123,1	163 446	0,15	3 189 271	2,97	4,2
Triticale	All - 2011	35 813 453	103,8	34 779	0,10	528 628	1,53	4,3
Oilseed rape	All - 2011	137 065 565	97,7	226 501	0,16	3 406 221	2,43	4,7
Durum wheat	All - 2011	31 152 045	89,8	45 757	0,13	615 096	1,77	4,5
Sugar beet	All - 2011	32 751 294	89,5	44 721	0,12	5 418 675	14,81	0,7
Soft wheat	All - 2011	389 485 556	84,8	532 894	0,12	9 689 327	2,11	3,8
Potato	All - 2011	8 283 386	58,3	9 333	0,07	619 205	4,36	1,3

Note to reader: in 2011, 389,485,556 g of glyphosate was spread on soft wheat crops. Soft wheat producers used an average of 84.8 g/ha during the 2011 crop year. A total of 532,894 treatments were made with a product containing glyphosate, and on average, soft wheat farmers performed 0.12 treatment with a product containing glyphosate. The total number of herbicide treatments on soft wheat in 2011 was 9,689,327, or 2.11 herbicide treatments on average for this crop. On average, 3.8% of herbicide treatments on soft wheat were made with a product containing glyphosate.

Species	Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
Sunflower	All - 2014	155 721 383	250,1	201 279	0,32	1 327 955	2,13	11,1
Protein pea	All - 2014	24 810 672	199,6	29 552	0,24	366 058	2,95	6,7
Triticale	All - 2014	48 183 684	131,9	43 979	0,12	610 609	1,67	5,4
Oilseed rape	All - 2014	187 712 878	130,8	279 459	0,19	4 273 603	2,98	5,1
Barley	All - 2014	210 833 815	128,3	294 732	0,18	3 673 226	2,24	5,8
Soft wheat	All - 2014	562 271 390	115,3	693 985	0,14	12 107 992	2,48	3,9
Grain maize	All - 2014	196 167 028	112,9	242 272	0,14	5 102 642	2,94	3,8
Sugar cane	All - 2014	2 912 475	104,9	18 251	0,66	100 649	3,62	17,3
Forage maize	All - 2014	132 388 530	102,3	140 738	0,11	3 825 698	2,96	3,3
Durum wheat	All - 2014	26 394 080	99,2	29 213	0,11	521 105	1,96	3,6
Sugar beet	All - 2014	30 902 335	80,4	42 894	0,11	5 381 519	14,00	0,9
Potato	All - 2014	7 444 911	50,1	9 270	0,06	581 802	3,91	1,2

N.B. Sugar cane (Guadeloupe and Réunion) in this table is only for 2014.

Vegetables

Species	Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
Melon	All - 2013	1 156 578	102,3	1053	0,09	6 509	0,58	5,6
Carrot	All - 2013	1 052 189	88,1	1297	0,11	68 829	5,76	1,5
Lettuce	All - 2013	1 194 079	62,8	687	0,04	9 874	0,52	2,6
Leek	All - 2013	158 282	33,7	137	0,03	9 805	2,09	1,0
Tomato	All - 2013	194 301	32,8	140	0,02	8 423	1,42	0,7
Other brassicas	All - 2013	126 786	23,0	86	0,02	3 603	0,65	1,3
Strawberry	All - 2013	34 893	17,6	45	0,02	1 285	0,65	1,3
Cauliflower	All - 2013	50 425	2,3	77	0,00	22 413	1,01	0,2

Note to reader: in 2013, 1,194,079 g of glyphosate was spread on lettuce crops. Lettuce growers used an average of 62.8 g/ha during the 2013 crop year. A total of 687 treatments were made with a product containing glyphosate and, on average, lettuce growers conducted 0.04 treatments with a product containing glyphosate. The total number of herbicide treatments on salad in 2013 was 9,874, or 0.52 herbicide treatments on average on lettuce. On average, 2.6% of the herbicide treatments on lettuce were made with a product containing glyphosate in 2013.

Arboriculture

Species	Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
Peach	All - 2012	11 974 257	1 009,95	8 588	0,72	19 873	1,68	30,2
Plum	All - 2012	13 363 878	722,09	16 153	0,87	27 265	1,47	48,4
Apricot	All - 2012	10 140 337	707,50	8 797	0,61	15 925	1,11	37,4
Cherry	All - 2012	4 281 860	506,59	4 430	0,52	7 182	0,85	38,6
Apple	All - 2012	19 276 154	482,53	26 877	0,67	74 420	1,86	27,5

Species	Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
Apricot	All - 2015	11 250 510	1 004,34	10 267	0,92	19 025	1,70	51,6
Peach	All - 2015	7 868 102	943,37	7 942	0,95	15 218	1,82	44,9
Banana	All - 2015	7 306 705	936,41	11 637	1,49	28 899	3,70	40,7
Apple	All - 2015	23 704 165	684,70	31 518	0,91	77 336	2,23	37,1
Cherry	All - 2015	3 892 147	641,66	4 574	0,75	6 870	1,13	57,3
Plum	All - 2015	7 405 508	482,87	17 157	1,12	27 029	1,76	59,3

N.B.: Banana in one of the two tables only.

Note to reader: in 2015, 23,704,165 g of glyphosate was spread on apple crops. Apple growers used an average of 684.70 g/ha during the 2015 crop year. A total of 31,518 treatments were made with a product containing glyphosate and, on average, apple producers conducted 0.91 treatments with a product containing glyphosate. The total number of herbicide treatments on apple in 2015 was 77,336, or 2.23 herbicide treatments on average. On average, 37.1% of herbicide treatments on apple were made with a product containing glyphosate in 2015.

Viticulture

Region	Total quantity of glyphosate used (g)	Average quantity of glyphosate used (g/ha)	Total number of glyphosate treatments	Average number of glyphosate treatments	Total number of herbicide treatments	Average number of herbicide treatments	Average share of glyphosate treatments (%)
All - 2010	**337 049 598**	**471,4**	**616 113**	**0,86**	**1 240 717**	**1,74**	**44,3**
All - 2013	**370 694 967**	**510,8**	**675 025**	**0,93**	**1 498 827**	**2,07**	**41,7**

Note to reader: in 2010, 337,049,598 g of glyphosate was spread on vineyards. Wine growers used an average of 471.4 g/ha during the 2010 season. A total of 616,113 treatments were made with a product containing glyphosate, and on average, wine growers conducted 0.86 treatments with a product containing glyphosate. The total number of herbicide treatments on vines in 2010 was 1,240,717, or 1.74 herbicide treatments on average. On average, 44.3% of herbicide treatments on vine were made with a product containing glyphosate in 2010.

Annexe C Table of common herbicidal active ingredients with their hazard statements

N.B.: With 120 references and many combinations with other herbicidal active ingredients, this table reflects the width of glyphosate's range of action and its availability in the public domain. The hazard statements underline the variously favourable profiles of the other molecules.

Name of active ingredient	Hazard statements[1]	Indicative number of commercial references with the active ingredient alone	Active ingredients available in formulated mixtures
Glyphosate	H318, H411	120	Diflufenicanil, 2-4 MCPA, Flazasulfuron, 2-4D, Dichloprop-p, Flufenacet, Pyraflufen-ethyl, Pelargonic acid
2-4 D	H302, H317, H318, H335, H412	10	2-4MCPA, Mecoprop-p, Dicamba, Clopyralid, Dichloprop, **Glyphosate**, Iron sulphate, Triclopyr
Pelargonic acid	H314	3	**Glyphosate**, Maleic hydrazide
Aclonifen	H317, H351, H400, H410	3	Clomazone, Flurtamone, Isoxaflutole
Carfentrazole-ethyl	H400, H410	5	Mecoprop-p, Metsulfuron-methyl, Flupyrsulfuron-methyl
Chlorotoluron	H351, H361d, H400, H410	10	Bifenox, Diflufenicanil, Pendimethaline, Isoxaben,
Clopyralid	H318	9	2-4MCPA, 2-4D, Florasulam, Fluroxypyr, Triclopyr
Dicamba	H302, H318, H412	7	2-4D, 2-4MCPA, Mecoprop-p, Bentazon, Bromoxynil, Prosulfuron, Iron sulphate, Tritosulfuron
Dimethenamide-p	H302, H304, H315, H317, H319, H400, H410	2	Quinmerac, Metazachlor, Pendimethaline
Flazasulfuron	H400, H410	4	**Glyphosate**
Flumioxazine	H360D, H400, H410	2	-
Fluroxypyr	H412	4	Aminopyralide, Clopyralid, Florasulame, 2-4MCPA, Triclopyr
Isoproturon	H351, H400, H410	8	Beflubutamide, diflufenicanil, flurtamone,
Metazachlor	H317, H351, H400, H410	6	Clomazone, Imazamox, Quinmerac, DMTA-P,
Metsulfuron-methyl	H400, H410	16	Carfentrazone-ethyl, Diflufenicanil, Florasulam, Thibenuron-methyl, Flupyrsulfuron-methyl, Thifensulfuron-methyl
Oryzalin	H317, H351, H400, H410	0	Isoxaben
Oxyfluorfen	H410	0	Pendimethalin, Propyzamide

Pendimethalin	H317, H400, H410	15	Chlortoluron, Diflufenicanil, Clomazone, DMTA-P, Flufenacet, Imazamox, Oxyfluorfen, Picolinafen
Propoxycarbazone	H400, H410	1	Iodosulfuron, Methyl sodium, Amidosulfuron, Mefenpyr dietyl
Propyzamide	H351, H400, H410	20	Aminopyralid, Oxyfluorfen
Prosulfocarb	H302, H317, H411	6	Clodinafop Propargyl, Cloquintocet-methyl, Metribuzin
S-metolachlore	H317, H400, H410	1	Mesotrione, Benoxacor
Sulfosulfuron	H400, H410	1	-
Thifensulfuron-methyl	H400, H410	3	Flupyrsulfuron-methyl, Metsulfuron-methyl, Thibenuron-methyl

[1] H302: Harmful if swallowed
H304: May be fatal if swallowed and enters airways
H314: Causes severe skin burns and eye damage
H315: Causes skin irritation
H317: May cause an allergic skin reaction
H318: Causes serious eye damage
H319: Causes serious eye irritation
H335: May cause respiratory irritation
H351: Suspected of causing cancer
H360: May damage fertility or the unborn child
H361d: Suspected of damaging the unborn child
H400: Very toxic to aquatic life
H410: Very toxic to aquatic life with long-lasting effects
H411: Toxic to aquatic life with long-lasting effects
H412: Harmful to aquatic life with long-lasting effects

Annexe D Document submitted by agricultural technical institutes reporting on difficult or critical situations

PROHIBITION OF GLYPHOSATE - DIFFICULT OR CRITICAL SITUATIONS

ACTA – French arable institutes

The objective is to identify situations where a glyphosate ban will engender significant difficulties. We have identified four categories of situations considered very difficult or critical (total absence of alternatives): invasive flora or flora of public health concern, sensitive crops, direct sowing under cover and situational uses imposed by pedoclimatic conditions.

Invasive flora or flora of public health concern

Common ragweed *(Ambrosia artemisiifolia) maybe giant ragweed (Ambrosia trifida)*: This weed is subject to mandatory control because of its allergenic pollen. This nuisance is reinforced by a long flowering period and the emission of highly abundant and easily disseminated pollen. Glyphosate can be used before spring sowing to eliminate early emergence (a control measure recommended by institutes and development stakeholders) and during intercropping to prevent flowering and ensure weeds do not go to seed. The critical situation concerns the impossibility of using glyphosate in this intercrop phase, as a catch-up, on ragweed that has developed following management during the cropping period and insufficiently effective post-harvest tillage.

Invasive flora: Glyphosate is used to manage invasive weeds during the intercrop period. We can cite here the large knotweeds (*Reynoutria japonica*, *Reynoutria sacchalinensis*, *Polygonum polystachyum*) as we have no other solution for these invasive species which enter fields of irrigated summer crops, or invasive alien plants that are dangerous for the loss of biodiversity they engender (for example, petasites, giant hogweed, *Impatiens glandulifera* etc.).

Sensitive crops

Fibre flax:
The retting process (progressive isolation of fibres in wet conditions through the disintegration of stems left on the ground) can be disturbed by several types of weeds which can cause windrows to warm up, interfere with turning or winding during harvesting and/or polluting the fibres produced. Yield and quality losses can be significant, even ruining the crop. These weeds are:

- Flax itself, whose capsules disperse their seeds and then germinate (almost no dormancy for some varieties) and invade the windrow.
- Creeping weeds such as knotweed, wild buckwheat, annual bluegrass, quackgrass, veronica, saltbush etc.
- Remnants of uprooted plants which have survived grubbing up, such as oilseed rape or goosefoot, whose axillary buds regrow.

Weeding is not systematically required during retting, but in cases where preventive strategies have failed (dry spring) it is essential. In 2017, of the 100,000 ha of fibre flax produced in France, 60% to 70% required weeding during the retting period.

Today, only diquat (under threat) and glyphosate have been available since the recent withdrawal of BASTA F1. Glyphosate is used at a maximum rate of 3 l/ha for a formulation at 380 g/l with the application taking place in July-August. There are no residue problems due to the non-food use of fibre flax.
France is the world's leading producer of fibre flax.

Lucerne (for seed)
In order to be certified, seed production must meet qualitative standards. The main difficulty is the respect for purity standards and, in particular, the absence of weed seeds in batches of seeds.

Minimum specific purity	Maximum % of seeds from other plants (GAP in French)	Weeds with particular standards
97% (pure seed)	1.5%	Docks, field dodder, wild oats, sweet clover

In lucerne many weeds are difficult to eliminate during factory sorting so control starts in the field. Weed control begins in the autumn when the cover crop finishes (sowing usually takes place in spring under sunflower). Since 2011, the registration of glyphosate-based herbicides (ROUND UP Innov, GIBSON etc.) has significantly improved the efficacy of weed control programmes in lucerne.

Glyphosate applied at a low dose (360 g a.i.s/ha) in winter during the vegetative rest period forms the basis of current weed control programmes. This active ingredient is particularly effective against certain multi-year or perennial weeds (ox-tongue, ribwort plantain, young docks etc.). Currently, no other solution is available.

Lucerne seed production has grown significantly in recent years. France is one of Europe's leading producers (alongside Italy) with around 24,000 ha dedicated to this crop in 2017.

Tobacco:

Tobacco growers are faced with the development of a parasitic plant, hemp (branched) broomrape (*Phelipanche ramosa*), mainly in two production zones: Alsace and the Poitou Charentes/Pays de Loire area. More than 70% of tobacco growers in these areas are concerned, i.e. more than 1,000 ha. After harvest, there are still some tobacco volunteers which allow hemp broomrape to continue its cycle and multiply. An application of glyphosate during the intercrop period on tobacco volunteers and host weeds, such as some asteraceae, makes it possible to halt the parasite's cycle and thereby limit the replenishment of the seed bank. In addition, the intercrop period is the best time to identify and halt the start of an infestation, a crucial step in avoiding the exponential growth of this parasitic plant in the following years (1 million seeds produced per foot). No other chemical or agronomic control method provides satisfactory results against this parasitic weed and the presence of hemp broomrape leads to fields being abandoned.

Direct sowing under permanent plant cover

Producers who use this type of system with no tillage and permanent soil cover are unanimous: the prohibition of glyphosate totally calls into question these types of practices.

Glyphosate is used to regulate cover crops and to manage weeds, including perennials, in the intercrop period. The doses applied vary from 1 to 3 l/ha (at 380 g/l) per intervention depending on the presence or absence of perennials. The systems are highly variable according to the crop succession in question. The figures below each present a real case showing the succession of crops and covers and the level of glyphosate use (blue rectangles) for each situation.

A survey of a group of producers monitored by Arvalis shows that it would be possible to limit the total dose to 1,500 g of glyphosate per hectare and per year by including rolling (for example, roller chopper) and the possibility of mixing it with broadleaf herbicides (carfentrazone, sulfos etc.). That is about half of the maximum dose per hectare and per year.

Feedback from these farmers indicates a saving in fuel use of around 18-25 litres per hectare and per year with direct sowing under cover crop systems compared to more than 100 litres per hectare and per year with tillage systems.

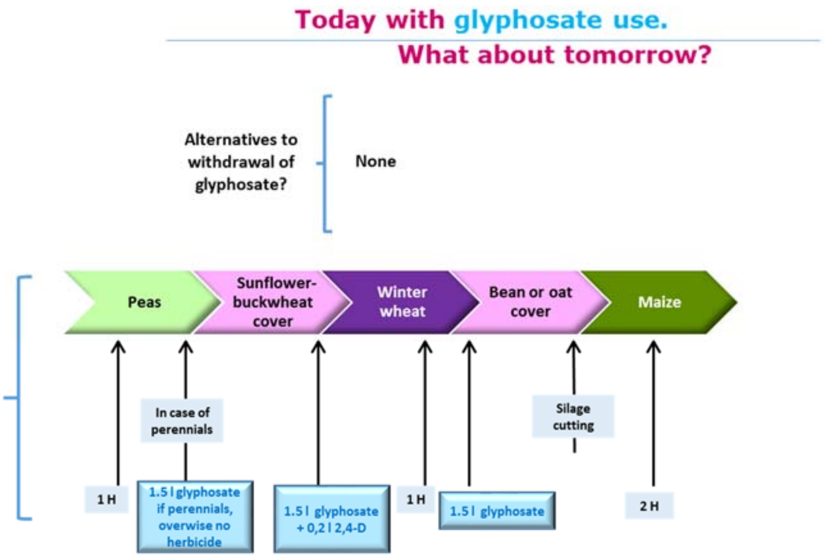
Situational uses imposed by the pedoclimatic context

Given the context of a humid winter and early spring, glyphosate use may be indispensable where there has been excessive rainfall or on soils sensitive to excess water (hydromorphous clay loams, for example) which rule out tillage during these periods. This is to prepare for sowing, i.e. to destroy weeds and cover in situations where herbicide use is allowed during the intercrop period, and also to transform temporary meadows in these situations. There are no alternatives because the other herbicides that can be used do not allow rapid sowing after application.

On soils with a high clay content, which cannot be reworked in the spring, the use of glyphosate (where this technique is allowed) to manage revegetation or cover crops makes it possible to plant spring crops. This is particularly the case in the Marais soils with high clay content found in the west of France (Brittany, southern Vendée and around Rochefort). Glyphosate is used before sowing, and can also be applied pre-emergence but post-sowing in maize, sunflower and soya, for example in combination with other herbicides (products available for this use). It should be emphasised that the fact that the soil is not touched before sowing avoids generating the emergence of new weed plants which then need to be controlled during cropping. This is also one of the principles of ragweed control.

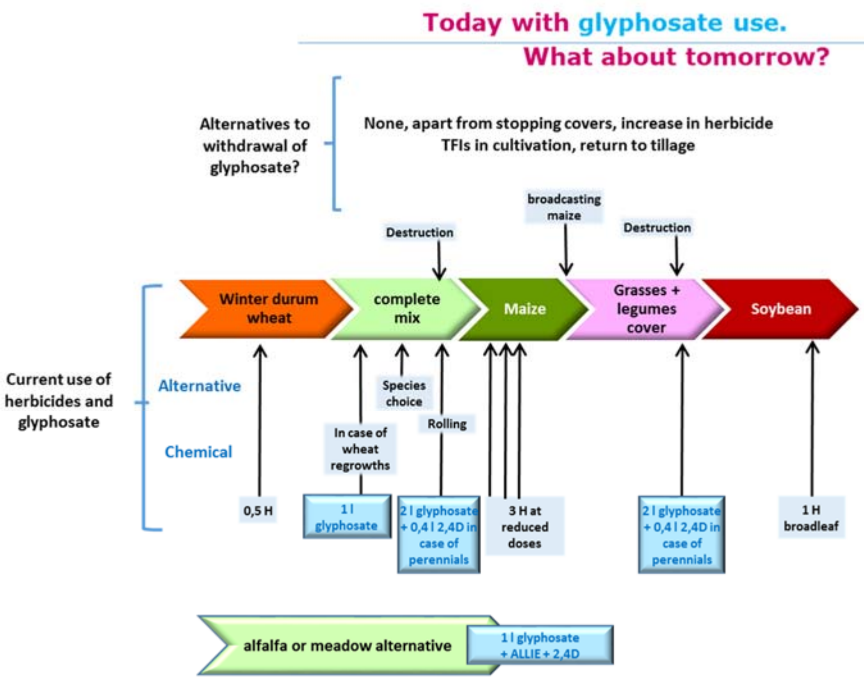
Another situation has been identified and could be analysed in terms of its occurrence. These are situations with low rainfall during the intercrop period. In these situations, glyphosate can be used to destroy regrowth and weeds without tilling the soil before sowing, which makes it possible to safeguard the soil’s freshness and ensure rapid crop establishment.

DIRECT SOWING UNDER COVER CROP



Case Study 1 (Poitou-Charentes)

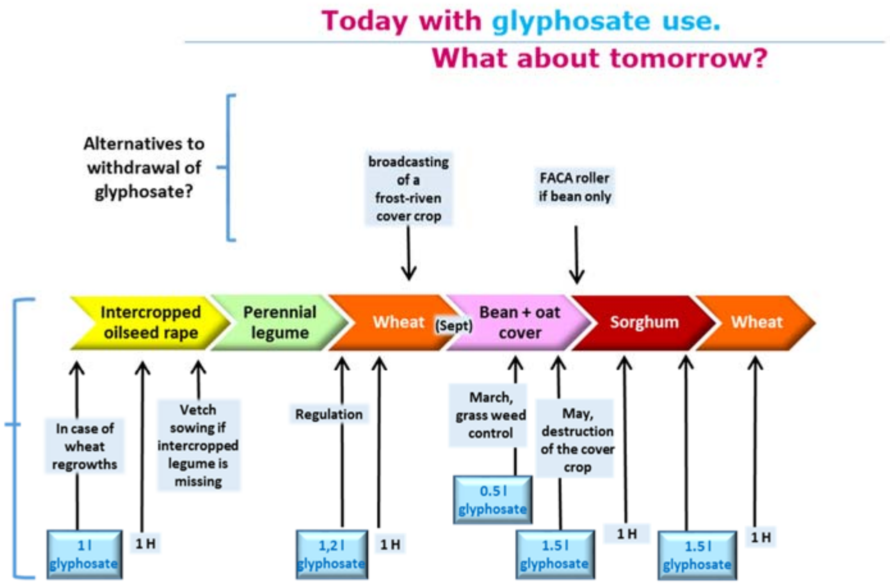
4,5 l of glyphosate over 3 years (540 g/year)



Case Study 2 (South France - Irrigated)

5 l of glyphosate 360 on the rotation = 1,67 l (600g of a.i) per ha and per year.

Small herbicidal TFI in crop



Case Study 3 (Center France – dry)

5,2 l of glyphosate 360 on the rotation = 1,3 l (325g of a.i) per ha and per year.

Limited alternatives (curved arrow)