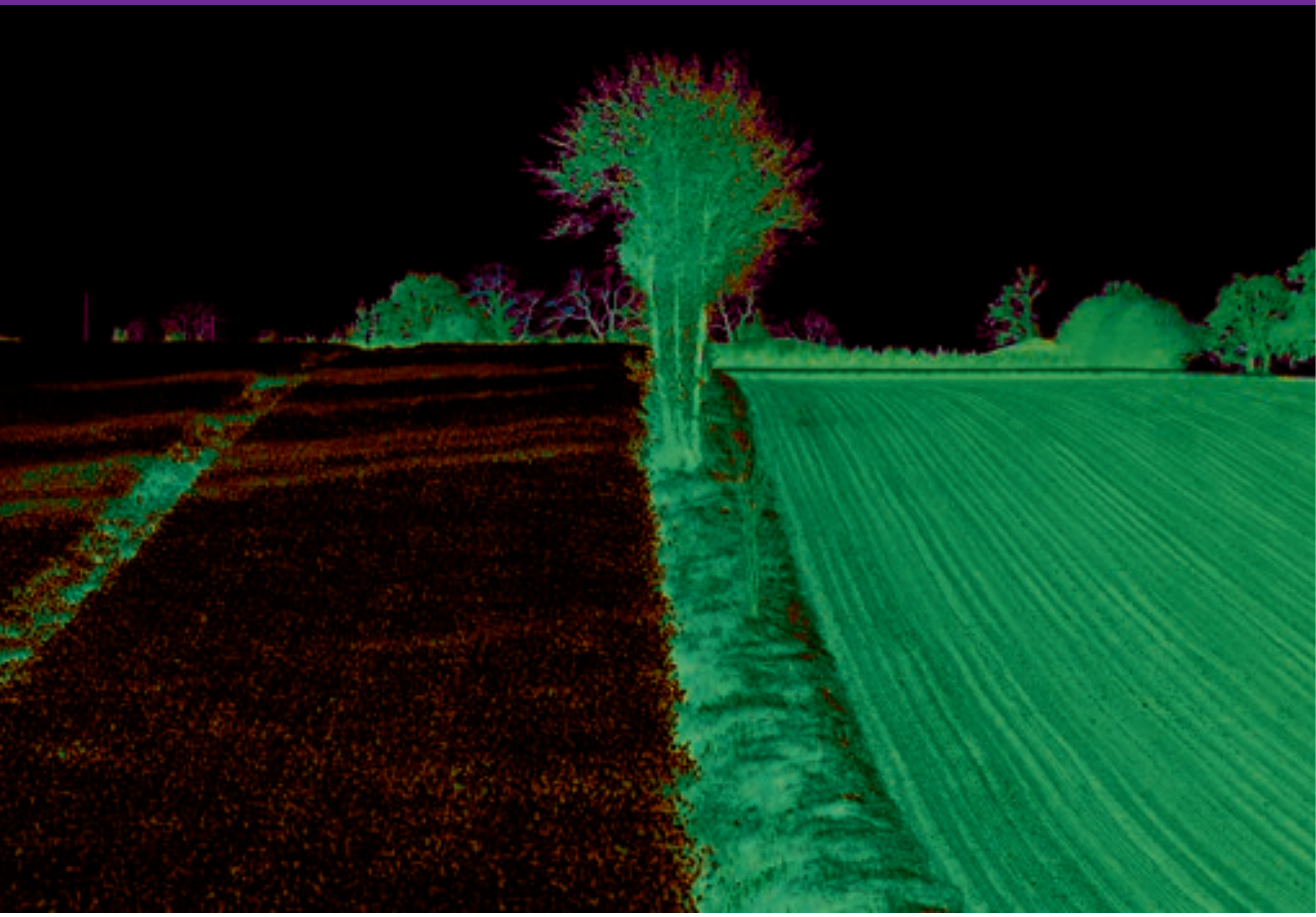
Practical guide
for the design of cropping systems less reliant on pesticides

Application in polyculture/mixed farming systems



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The practical guide for the design of cropping systems less reliant on pesticides – Application in polyculture/mixed farming systems, also named « STEPHY[a] guide » can be downloaded from the :

• Joint Technology Network for Innovative cropping sytems website
www.systemesdecultureinnovants.org

• ENDURE Network of Excellence website
www.endure-network.eu

• French Ministry of Agriculture website
www.agriculture.gouv.fr

A calculator is offered in conjunction with this guide. The calculator and the instructions for its use (both in French), can be downloaded from the Joint Technology Network for 'Innovative Cropping Systems' website :
www.systemesdecultureinnovants.org
and from the French Ministry of Agriculture website :
www.agriculture.gouv.fr/ecophyto-2018

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Contents

List of abbreviations

The terms in this list are marked by the ª sign in the text.

CMP	Crop management plan
CORPEN	(Comité d'Orientation pour des Pratiques Agricoles Respectueuses de l'Environnement) French steering committee for agricultural practices which respect the environment
CS	Cropping systems g [1]
CT	Conservation tillage
DSS	Decision support systems
F	Farm
IBIS	(Intégrer la Biodiversité dans les Systèmes d'exploitations agricoles) Integrating Biodiversity Into farming Systems; CASDAR project 2008-2010, led by the Centre Region Chamber of Agriculture
IC	Intercrop period
ICS	Innovative cropping system
IOBC/WPRS	International Organisation for Biological and Integrated Control of noxious animals and plants – West Palaearctic Regional Section
ITCF	(Institut Techniques des Céréales et des Fourrages) technical institute for cereals and forage
N	Nitrogen
OF	Organic farming
OM	Organic matter
SAN	(Réseau Agriculture Durable) Sustainable Agriculture Network
RMT	(Réseau Mixte Technologique) joint technology network
RSA	(Revue Suisse Agricole) Swiss Journal of Agriculture
STEPHY	(Stratégies de Protection des Cultures Economes en Produits Phytosanitaires) strategies for crop protection less reliant on pesticides
SdCi	(Système de culture innovant) innovative croppping system
TFI	Treatment Frequency Index

[1] The indication g in the text refers to the terms in the glossary

Preface

The goal of this guide, say the authors, is 'to offer an approach for the design of cropping systems less reliant on pesticides'. This involves, they add, 'going beyond a simple improvement in the efficacy of treatments...This means profound changes to the cropping system and the adoption of alternative practices for the management of pests, making it possible right from the early production stage to limit health risks.'

The expansion in the use of plant protection products in arable crops in the 1970s and 1980s led to an unprecedented standardisation in farm advice. There was only one 'good' way to produce wheat in the whole of Western Europe. It was based on the intensive use of pesticides and the control of all limiting factors to ensure maximum yield: sowing as early and as densely as possible ('one plant, one spike, primary tillers only'), feeding the crop with mineral elements to eliminate want ('good wheat should always be green, very green'), and ensuring total crop protection, eliminating weeds before emergence and diseases before symptoms are visible. The preventive use of plant protection products had become all the more necessary as short rotations, very early sowing, high crop densities and the ad lib application of nitrogen raised plant health risks. Chemistry offered to solve all crop problems. Pesticides became a cornerstone of cropping systems.

The approach offered in this guide puts agronomy back at the centre of our thinking on agricultural practices. In fact, agronomy offers not only technical solutions to limit pest populations, but also a framework for a systems approach to choosing techniques suitable for each situation and to combine them for synergies. The authors of this guide say, 'There is no 'typical' example of effective combinations for managing pests: these combinations are to be constructed case-by-case, according to the means available and the particular constraints faced'. It is a renewal based on diversity: biological diversity (long rotations, polyculture, beneficials) makes its comeback in the fields and diversity in crop management is back in the farm advisory sector.

This guide counts on inventiveness, the independent thought of the actors in the field. It offers a way of developing, in a complementary fashion, local knowledge, technological innovations and scientific knowledge. It formalises a framework for an approach based on an understanding of the specific local situation. It brings together farmers wishing to change their systems and their advisers who help them envisage alternatives. Together they combine, adapt and evaluate whether these alternatives will generate gains or losses in economic, ecological or organisational terms. This guide challenges the professional practices of farmers and their advisers. For farmers, it suggests they can learn to avoid many treatments which seemed necessary. For advisers, it offers the chance to no longer be the mere keepers of technical truths but facilitators, aiding farmers in their thinking. Crop revolution comes with a cultural revolution!

This guide is the result of teamwork during which every partner from research, training, ministries and farm advisory services contributed their knowledge and know-how to create a consensus. The result of this inter-institutional dialogue is a document which brings together, in a most remarkable manner, both practicality and scientific pertinence. We thank CORPEN (France's steering committee on environmentally friendly agricultural practices), emanating from the Ministries of Agriculture and Ecology, for having initiated this teamwork. We hope the new institutions which will replace it will be as productive as CORPEN has been since its creation in 1984, and will allow us to have in the future new tools, as relevant as this one, to help agriculture adapt.

Jean-Marc MEYNARD
Director of Research, INRA

July 2010

Glossary

Allelopathy
All effects direct or indirect, positive or negative, of one plant or micro-organism on another, through the release of biochemical compounds in the environment [1][1].

'Alternative' protection
A crop protection strategy in which we seek to replace chemical control with another means of protection [18]. For example, it could consist of replacing chemical control with biological control for managing insect pests, using genetic control[g] against diseases or using mechanical weeding against weeds.

Avoidance
Avoidance strategies consist of avoiding the concurrence between the contamination phase of a pest and the period when the crop is susceptible to attack. The principal lever is to consider the sowing date, coupled with the choice of suitable varieties.

Beneficials
Beneficials are the natural enemies of pests[g], parasites or predators which contribute to regulating pest populations.

Biofumigation
This practice consists of growing certain plant species chosen for their toxic potential for soil-borne pests [2] in the fallow period, then shredding and ploughing them in at a given stage. It relies on the use of plants rich in glucosinolates, principally crucifereae (such as mustard and radish). During decomposition, these molecules transform into volatile molecules which are toxic for certain soil-borne organisms [3].

Biological control
Biological control uses living organisms to prevent or reduce damage[g] caused by pests [13]. Examples include the use of Trichogramma wasps in maize and the use of Contans against sclerotinia.

Biotrophic
This distinguishes an organism which lives or feeds on a living cell.

Chemical control
Chemical control consists of using pesticides to protect crops.

Cover crop
A crop planted during the fallow period[g], between two production crops (for example, intermediate nitrate trap crops, green manures and catch crops).

Crop loss
Losses, both direct and indirect, in terms of both quantity (yield losses) and quality (changes in storage qualities, the visual aspects of a product etc.) caused by pests in a crop. We also talk of 'damage'. This idea should be distinguished from 'yield loss'[g], which concerns only losses in quantity [6][15][16].

Crop Management Plan (CMP)
A coherent and orderly combination of techniques used in an agricultural field with the aim of producing a crop [11]. This concept emphasises the coherence and interactions among a suite of farmer's practices [12].

Crop sequence
Cf. 'rotation'.

Cropping system (CS)
Set of technical procedures used in those fields which are managed in an identical way. Each cropping system is defined by the nature of the crop, the crop sequence and the Crop Management Plan applied to these different crops [8].

[1] *The numbers in brackets refer to the bibliography, which can be found at the end of the guide.*

Glossary

Cultural control

Cultural control includes all those control methods apart from chemical control[g], biological control[g], genetic control[g], and physical control[g]. It consists of adapting the cropping system[g] to limit the injury[g] caused by pests and to this end relies notably on modifying rotations, sowing date and density, the appropriate management of fertilisation and the management of tillage practices [5] [6].

Damage

Crop losses[g] (reduction in yield in terms of quantity and/or quality) due to an attack by a pest on a crop [5][6]. In this guide we use the term 'harvest damage' for this concept.

Fallow period

The period between the harvesting of one crop through to the sowing of the following crop.

Genetic control

Genetic control is the use of plants bred for their resistanceg, their toleranceg or their physiological characteristics for controlling pests [7].

Incidence

In this guide, the percentage of plants subject to injury[g] at the field scale [9].

Injury

All visible or measurable deviations compared to a healthy plant (symptom) caused by the presence of a pest on a crop (yellowing, necrosis etc.) [5] [6]. In this guide, we use the term 'observed injury' to indicate this concept.

Inoculum

The generic name describing all the elements of a parasite capable of contaminating a host [10].

Integrated Crop Management

A system for the control of organisms harmful to plants using a range of methods which satisfies, at the same time, economic, ecological and toxicological demands, and gives priority to the use of natural means for limiting pests [13].

Integrated production

An agricultural system for the production of food or other high quality products which uses natural resources and control processes to replace inputs damaging to the environment and ensures viable agriculture in the long term [13].

Intercropping

The planting of a crop between the rows of another crop of a different species.

Loss

Economic loss due to a pest attack on a crop. The origin may be a reduction in yield and/or a reduction in the quality of the crop following a pest attack [6]. A distinction should be made between this idea and those of 'crop loss'g and 'yield loss'[g] [15].

Means (or method) of alternative control

A control method other than chemical control: genetic control, cultural control, biological control or physical control.

Mitigation through crop status

Mitigation through crop status seeks to minimise injury[g] when crop and pest come into contact. This process works through modifying the canopy, that is to say increasing the competiveness of the crop and avoiding conditions which favour the development or propagation of pests[g] through sowing date or sowing density, through fertilisation, irrigation and the introduction of combinations of species and varieties.

Pests

Organisms which can cause damage[g] to crops. They can be pathogenic agents which cause disease, animal pests or weeds.

Glossary

Preceding crop effect

Preceding crop effect represents the variations in the state of the environment in a field between the start and end of a crop. This idea is tied in with that of 'susceptibility of the following', defined as 'the range of reactions of a crop to the diversity of environmental states left by the previous crop' [8].

Prevention

The set of measures (physical, varietal and cultural) to prevent the appearance of pests or to minimise their effects. Prophylaxis.

Physical control

Physical control uses mechanical, thermal, electromagnetic or pneumatic methods to control pests. For example, the use of mechanical weeding in arable crops [6][7].

Push-pull strategy

A strategy which consists of attracting crop pests at certain points in the landscape through the management, in a methodical manner, of crops, making it possible to attract or repulse pests. It makes it possible to distance cultivated plots from pest populations and avoid pest injury[g].

Remedial solution

A remedial solution is a lever for managing pests which can be used as a last resort in situations where the other levers used have not given sufficient results. It could be, for example, a remedial chemical control or mechanical weeding.

Resistance

All phenomena in a plant which prevent or limit the development of a pest [10].

Rotation

'The methodical succession of crops in a field, reproduced in a similar manner over the course of time. When the latter condition is not respected, one prefers to use the term crop sequence' [46].

Saprotrophic

In this guide we use the term 'rotation' to designate a succession of crops planned over a period of time, after which a priori the succession is reproduced, and the term 'crop sequence' to designate the succession of crops actually carried out.

Severity

Denotes an organism which feeds by absorbing nutrients from dead cells.
The percentage of the surface attacked on a plant that has been subject to injury[g] by a pest [9].

Sowing periods

Four crop sowing periods are classically used in France :
- 'early autumn' (end of summer/start of autumn : for example, oilseed rape)
- 'late autumn' (end of autumn : for example, wheat)
- 'early spring' (start of spring : for example, spring peas)
- 'late spring' (end of spring : for example, maize) [14].

Tolerance

The ability of a plant to limit the damage[g] caused by injury[g] from a pest.

Undersowing/oversowing

Sowing of a new crop following the earlier planting of a cover crop. The second species will not reach maximum development until the cover crop is harvested.

Yield loss

Losses in quantity (reductions in yield) caused by crop pests [6] [15] [16].

Introduction

GOALS OF THE GUIDE

For the past four decades, crop protection has essentially relied on the use of pesticides. Today, this strategy faces a number of challenges :

→ **Agronomic :** resistance to pesticides has developed in some pests[g1], leading to an erosion in the efficacy of products, or even a technical impasse in some situations. In addition, the reduced availability of products means that farmers have to turn to alternative crop protection methods.

→ **Health :** the use of pesticides carries a health risk, from farmers directly exposed through to consumers exposed to a lower degree via pesticide residues in agricultural products and water.

→ **Environmental :** the impact of pesticides on biodiversity and water, soil and air pollution no longer needs to be demonstrated.

Cartoon by Robert Rousso in Le Courrier de l'environnement from INRA n° 36, p. 95

→ **Economic :** the use of plant protection products guarantees a certain yield level by protecting crops from pest injuryg. Nevertheless, reducing their use by introducing alternative pest management practices can reduce the costs of using plant protection products without major reductions in yields. Furthermore, given the variability in agricultural prices and the several years that are needed to introduce a coherent cropping system, it seems logical to free farmers from annual economic fluctuations by developing systems which are robust irrespective of the price context [17][2].

→ **Regulatory :** the Water Framework Directive commits European Union Member States to achieve 'good status' for all water bodies by 2015. Under the new regulation EC 1107/2009, many active substances have been removed from the market and more will follow. The Framework Directive on the Sustainable Use of Pesticides (2009/128/EC) requires all European Union Member States to adopt a national action plan with a view to reducing the risks and effects of pesticide use and to encourage the development and introduction of Integrated Pest Management.
Faced with these challenges, **we need to find ways to sustainably reduce the reliance of cropping systems on pesticide use.**

[1] The indication g in the text refers to terms which can be found in the glossary.
[2] The numbers in brackets refer to the bibliography, which can be found at the end of the guide.

Introduction

This guide was created by a working group launched through an initiative of CORPEN[a] , the STEPHY group (STratégies de protection des cultures Economes en produits PHYtosanitaires, strategies for crop protection less reliant on pesticides). Its objective is to **facilitate a learning process on the design of cropping systems less reliant on pesticides and is based on alternative strategies for protection against pests**. Its ambition is to **help advise and train farmers and farm advisers wishing to move towards agricultural practices which consume fewer pesticides**. It is dedicated to arable crops, though the method it describes can be extrapolated for other farming systems such as mixed crop-livestock farming, agriculture in controlled environments, and even perennial crops.
This guide offers **a learning process** for the construction of these systems **rather than technical solutions to be introduced**. It highlights, in particular, work conducted in the ADAR Systèmes de Culture innovants (innovative cropping systems) project and the current work of the RMT[a] Systèmes de Culture Innovants (joint technology network for innovative cropping systems).

STRUCTURE OF THE GUIDE

The guide comprises two parts.
The first part covers **basic concepts** concerning crop protection and describes alternative strategies for crop protection. This section has been largely inspired by the ECOPHYTO R&D programme [17] and by a collective scientific expertise on pesticides [6], which provides an overview of current knowledge and experience in this sphere. It also builds on the expert knowledge of the guide's authors and of external experts, who were consulted when needed.
The second part offers a step by step **learning process for designing cropping systems less reliant on pesticides** to be used **with** farmers. The first step is to describe the context in which the system is situated, and the system itself, highlighting its advantages and disadvantages with regards to pest management. The co-design step helps users construct, starting from the initial cropping systemg, alternative cropping systems less reliant on pesticides. The final step is to evaluate the performance of these systems compared to the initial system according to diverse criteria including level of pesticide use, nitrogen balance, amount of energy used and socio-economic criteria.

The boxes in the text provide the views of farmers (marked with an F) and advisers (marked with an A) and are taken from interviews conducted with farmers and advisers on the design and introduction of systems less reliant on inputs.

Throughout the second part of the guide, we refer to three types of tools for aiding farmers and their advisers in the design stage (see the annex sections of the guide) :

- **Support sheets : rapid programme/comprehensive programme**

Practical information for using the suggested programme, they are to be consulted as and when needed during the design; afterwards they can be given to farmers to provide a reminder of the discussions held.
The sheets form an interview questionnaire to be used with farmers and are found in two different sections, corresponding to the two types of programme offered.

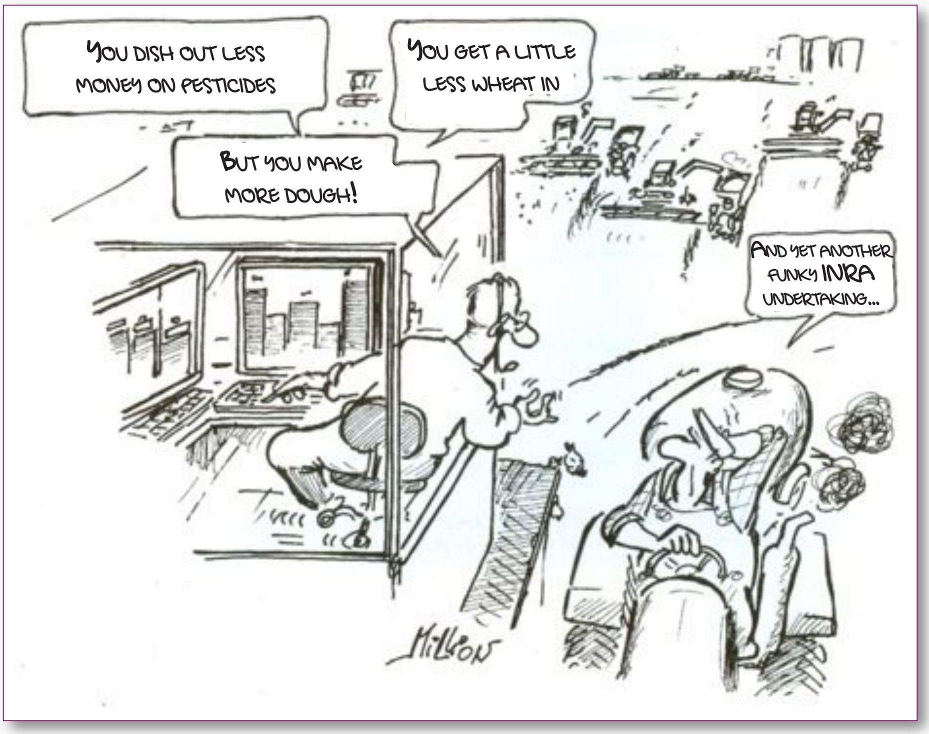
- **Help sheets**

These contain information (tables, graphs) useful in the design process.

- **The STEPHY[a] calculator**, created to accompany the programme, can replace certain information sheets, notably for describing farmers' practices. Among other things, using the the calculator makes it possible to conduct a rapid evaluation of both cropping systems to be improved and new proposed cropping systems. It is available, in French, on the RMT SDCI[a] (joint technology network for innovative cropping systems) website (http://www.systemesdecultureinnovants.org/).

[1] *The indication a in the text refers to abbreviations which can be found in the list of abbreviations.*

Introduction



Cartoon by Robert Rousso in Le Courrier de l'environnement from INRA n° 37, p. 86

In this guide we provide a complete programme for the design, with farmers, of cropping systems less reliant on pesticides. Nevertheless, we are aware that the complete programme may not always be possible due to time constraints, lack of resources or the involvement of farmers in the process. Therefore, for each step of the programme we offer two levels:

→ A **'comprehensive programme'**, which provides the complete set of steps.

A **'rapid programme'**, which offers a simplified approach. Nevertheless, it should be borne in mind that the rapid option is less precise, notably regarding the diagnosis and evaluation of current and alternative cropping systems. It has been designed as a programme to encourage exploration of cropping systems less reliant on pesticides and, we hope, to provide encouragement for more thorough work at a later stage.

HOW TO USE THIS GUIDE

The guide addresses reducing the use of plant protection products in arable cropping systems **at the field scale and over the course of the crop sequence**. Ways to reduce the use of these products at the farm or landscape scales are not addressed in detail. However, the box on page 39 provides a quick description of such options.

Neither do we address practices based on the rational use of pesticides such as avoiding systematic treatments, applications based on threshold levels, reduced doses and the use of forecasting models, nor safe use, storage and disposal practices to reduce health and environmental risks. While these practices can reduce impact and can represent a first step towards a reduction in pesticide use, they do not permit significant reductions in pesticide use or reliance. **The objective here is to go beyond improvement in the efficacy of treatments or substituting currently used products**. Rather, the guide seeks to reduce the dependence of cropping systems on pesticide use. This means a more profound change to the cropping systemg and adopting alternative pest management practices[g] that make it possible to limit health risks from the outset [18][19].

Also, within the programme described here, we offer ***a priori*** **evaluation** of the systems which are designed. **Monitoring and evaluation of innovative systems once they are introduced are not within the scope of this guide.**

Introduction

On the one hand, this guide is designed **for use by groups of farmers or farm advisers during training**. It describes some of the fundamentals of crop protection and illustrates the various concepts raised via examples, help sheets and annex II on 'typical' crop management plans. It suggests a set of steps to facilitate a learning process.
On the other hand, it is also **designed to be used on the farm by farmers and their advisers** (or maybe farmers working on their own initiative) to **explore alternative systems to those currently used**. Above all, it is the second part of the guide and the support sheets which cover these aspects. The time necessary to complete the programme is estimated to be between **half a day and one day** for a cropping system, according to the programme used. When doing this, it is useful for farmers to have to hand records of their practices and farm accounts.
This time does not include the time required to read and understand the entire guide, which advisers should do in advance.

The underlying goal of the guide is to describe and facilitate a learning process rather than provide technical solutions. It is meant to be used in combination with the sheets describing in more detail the introduction of the practices mentioned. These sheets are already available for the management of weeds. They will be completed by the work currently being undertaken by the RMT SDCIa concerning the management of other pest categories (diseases and animal pests) and will be available as and when completed on the RMT website (http://www.systemesdecultureinnovants.org/).

PART I : SOME FUNDAMENTALS OF CROP PROTECTION

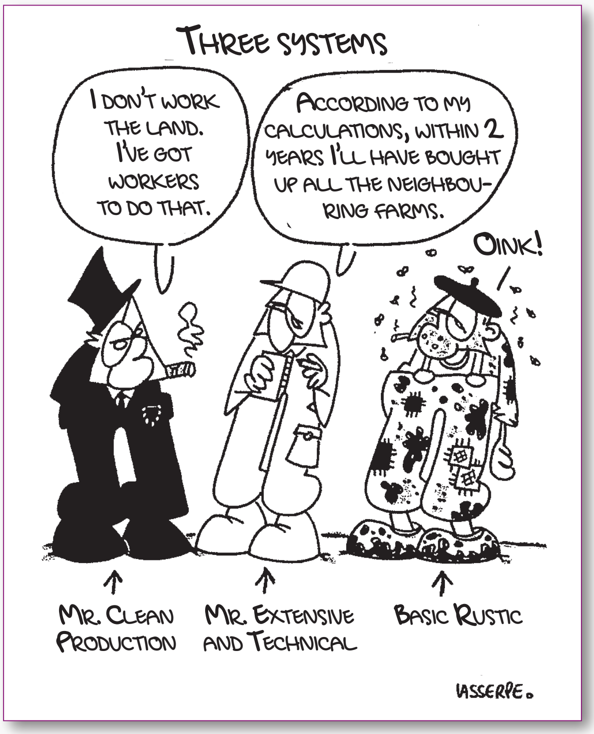
I. INTEGRATED CROP MANAGEMENT AND DIFFERENT STRATEGIES FOR CROP PROTECTION

In the learning approach proposed in this guide, the objective is to reduce the use of plant protection products in a cropping system, while monitoring other elements of the system such as nitrogen and energy consumption or maintaining an appropriate income for farmers. The programme therefore falls within the scope of integrated production. This concept has several definitions, and we use that given by the IOBC-WPRS in 1973 [13] :
"An agricultural production system for food and other products of high quality which uses natural resources and regulating mechanisms to replace inputs damaging to the environment and which ensures the long-term viability of agriculture."
Plant protection is only one of the facets of crop production, which must address in a coherent fashion all the elements of the system such as pest management, nitrogen, and energy consumption. It would be inappropriate to develop a plant protection strategy without taking all these elements into account. That is why, in this guide, **we place ourselves within the framework of integrated production without limiting ourselves to Integrated Pest Management.**
Table 1 describes various approaches to crop protection relative to 'integrated production'.

Table 1 : Functional approach of various crop protection strategies

	Systematic protection	Supervised chemical control	'Alternative' protection*	Protection within an integrated production system
Objectives	Limiting observed injury[g] Systematic use of pesticides	Reduction of economic losses[g] by limiting harvest damage[g] Optimisation of pesticide use	Reduction of economic losses[g] by limiting harvest damage[g] Introduction of pesticide substitution techniques	Reduction of economic losses Use of combinations of control methods from alternative to chemical control, whilst ensuring sustainable management of other production resources (nitrogen, energy etc.)
Control methods used	Chemical control[g]	Chemical control[g]	Chemical control[g] or alternative control[g]	All alternative and chemical methods
Time scale used	Seasonal or annual	Seasonal or annual	Seasonal or annual	Over several years (crop sequence)
Spatial scale used	Field	Field or spot spraying (precision agriculture)	Field	Crop pattern and local area
DSSa used	Predefined treatment plans Chemical protection programmes	DSS for adapting date, dose, opportunities for treatment Observations, official recommendations	Observations DSS for choosing alternative techniques	Observations DSS for choosing alternative techniques DSS for adapting doses and opportunities for chemical treatments DSS for assessing remedial technique opportunities DSS to manage spatial crop pattern N.B.: not all of these tools are currently available

The chapters which follow examine the ideas used in this table in more detail.



Cartoon by Lasserpe in Le Courrier de l'environnement from INRA n° 47, p.24

II. NOTIONS OF 'INJURY', 'DAMAGE' AND 'LOSS' [5] [6][15]

Without taking any plant protection measures, pests would cause considerable yield losses compared to the yields currently achieved. It is therefore easy to understand the care which growers devote to this aspect: they seek to protect themselves from losses in revenue as much as possible, and to do this they seek to limit crop losses. Pests are therefore strictly controlled as part of a strategy focused on securing production.

However, **it is important to make a distinction between the ideas of 'injury'[g], 'damage'[g] and 'loss'[g]. Injury** is the observation of the impact of a pest population on a crop **(observed symptoms).**

By **damage** we mean **crop losses**, in terms of **quantity or quality,** due to the action of a given pest. The idea of loss refers to the **economic loss** engendered by the damage.

Injury does not necessarily lead to damage, nor to loss, because it depends on the link between the injury and the phase of the crop's development in terms of quantity and quality. The curve showing the damage function can be seen in Figure 1 and illustrates this idea: below a certain level of injury, damage remains low.

In the same way, damage does not systematically lead to economic loss. For example, signs of scab on produce are not necessarily reflected in their price when they are sold in the organic sector.

To clearly distinguish between these ideas in the guide, the terms **'observed injury', 'harvest damage' and 'economic loss'** are used.

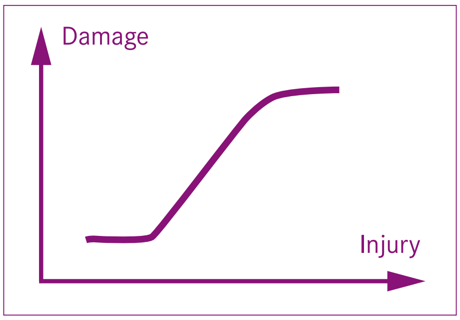


Figure 1: Illustrating the damage function

Figure 2 illustrates these ideas.

The transition between injury and damage depends on the crop's development stage and as a function of the injury (crop loss as a function of the quantity of observed injury). The transition between damage and loss depends on socio-economic factors (value of the crop harvested etc.) and as a function of the loss (economic loss as a function of the amount of damage).

Therefore, while systematic crop protection methods veer towards limiting observed injury to avoid harvest damage, **the approach used in this guide favours the limitation of economic losses while tolerating a certain level of injury and damage.**

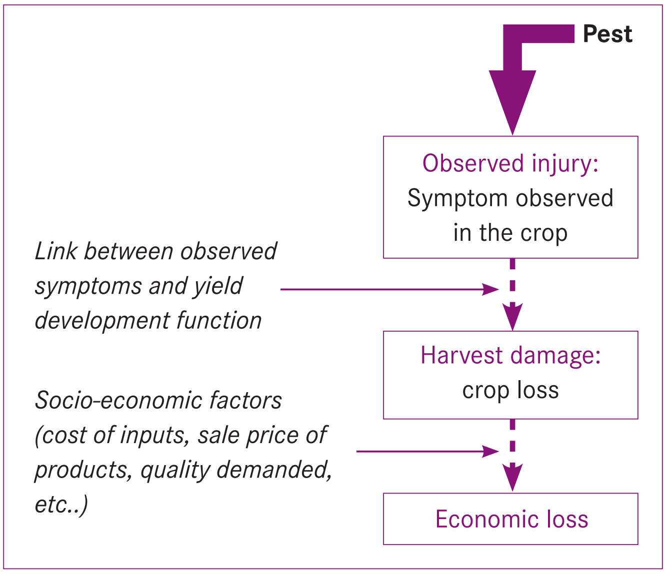


Figure 2 : The relationship between 'injury', 'damage' and 'loss' [16]

In fact, it is sometimes possible to use fewer inputs, and therefore tolerate damage, while maintaining the same economic margin in the system, the reduction in costs compensating for any harvest damage (except in situations where prices for agricultural products are high or prices for inputs are low). An example of this can be seen in the French 'hardy wheat' network, where the TFI[a] has been reduced by 40% without any reduction in farmers' revenues [17].

Source: D. Robert (ITCF) – Average of 27 trials in northern Picardy and Normandy, 2009.
This graph illustrates the fact that increasing the level of inputs in a given field can make it possible to increase the harvest obtained, but not necessarily the economic margin in the system.

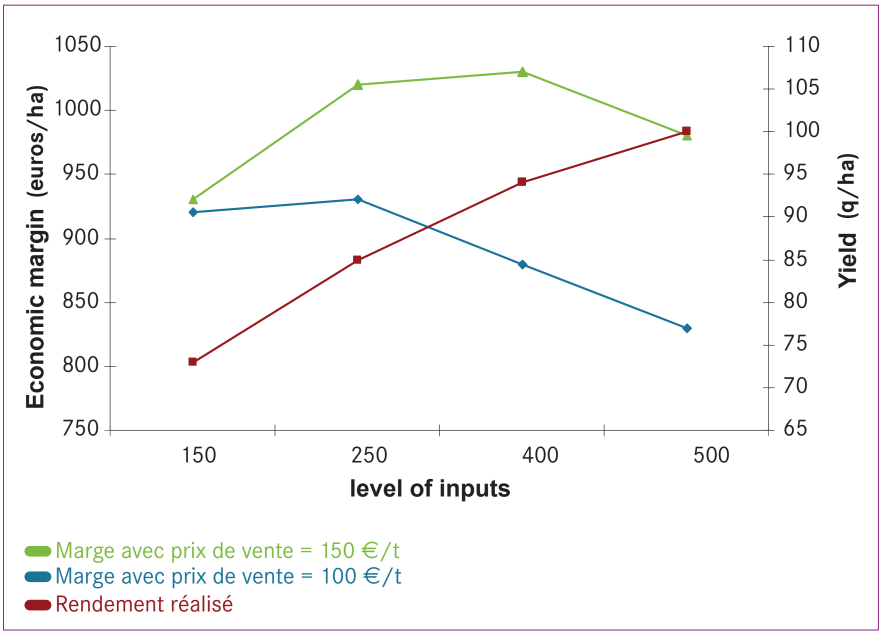


Figure 3: Variations in gross margins achieved as a function of different levels of inputs and different price scenario

III. EXISTING CROP PROTECTION METHODS

III. 1. Types of pest control methods

Reducing economic losses[g] caused by pests[g] can be achieved using different methods. These methods are divided into five broad categories, which are illustrated in the following diagram.
In this diagram, and in the text which follows, we use the term **'control'** for all methods of managing pests, from avoiding injury (preventive methods) which is relevant for disease prevention and control methods which act on the pests when they are already in the field (limiting injury - curative methods).

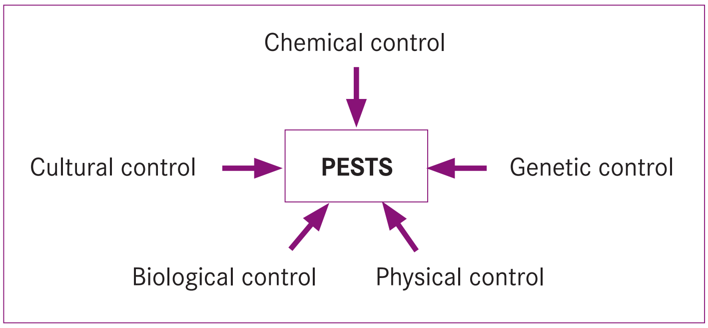


Figure 4: Pest control methods [6]

Chemical control[g] involves the use of pesticides. It is the most common control method used today, alongside **genetic control**[g], which involves the use of plants bred for their resistance[g], tolerance[g] or physiological characteristics relative to pests. A crop protection strategy less reliant on pesticides is the result of combinations of these methods and others. Among the latter, are **biological control**[g], which involves the use of living organisms to prevent or reduce harvest damage caused by pests (for example, the use of *Trichogramma* in maize) and **cultural control**[g]. The latter consists of adapting the cropping system[g] to limit the damage caused by pests. It uses adaptations of any cropping practice, such as crop sequence, tillage practices, date and density of sowing and fertilisation. This type of protection boosts **prevention**[g] since it avoids conditions conducive to pest contamination and development in crops, rather than seeking to control pests once they are already present in the field.
Agriculture also employs techniques which are categorised as **physical control**[g]. The definition of this term includes thermal, electromagnetic and pneumatic means, but in arable crops it is principally the introduction of mechanical means of controlling pests. An example is mechanical weeding such as hoeing in sunflower crops.

With the exception of plant breeding, work on the pest control methods described above has been limited. One reason has been the absence of economic drivers for their dissemination and use. While experimentation has been conducted on some topics (for example, on the effect of tillage on weeds), **there are few references available on bringing these various levers together in a coherent way in crop protection strategies. Chiefly, the information we have available is derived from various experiences** (notably in organic farming).

To sum up, the majority of **current protection strategies are based on the use of pesticides to limit pest injury. A significant reduction in pesticide use involves redesigning cropping systems to limit the risks in anticipation rather than after they occur** [18]. The aim of this guide is to help build such systems.
All the methods as well as their modes of action on the three categories of pests are succinctly presented in the pages that follow. More in-depth information on their introduction and their knock-on effects are available in the sheets produced by RMT[a].

III. 2. Existing alternative control methods [44]

Alternative management methods seek to introduce a set of methods which act at different stages of the pest and crop cycles and therefore contribute to limiting the incidence[g] of pests, their development and contamination of the crop (cf. Figure 5). By 'alternative method' we mean all methods other than chemical control: genetic control[g], physical control[g], biological control[g] and cultural control[g].

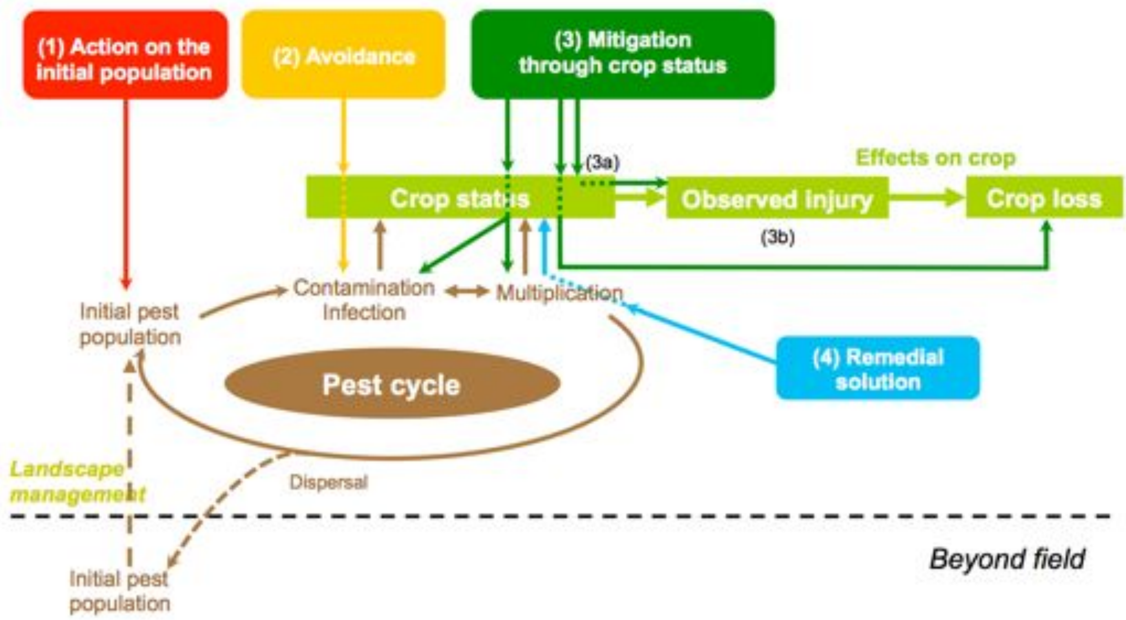


Figure 5: Positioning different levers for pest management
The term 'crop status' here includes the crop structure, its density and its development stage.

These methods rely on practices which act at different stages in the pest and/or crop cycle. Upstream, the methods can be used to **act on the initial pest population** (1) and limit the development of populations which are the source of crop contamination. It is based on adapting the crop sequence and tillage (including the management of crop residues) and, possibly, biological control.

Through the crop's development cycle, the methods which can be used are based on **avoidance strategies[g]** (2). These consist of avoiding any concurrence between the phase when a pest can contaminate a crop and the period when the crop is susceptible. The principal lever is, therefore, planning of the sowing date. **Mitigation through crop status strategies[g]** (3) can also be used. The objective of these is to minimise injury when the crop and pest come into contact. They work mainly by modifying crop status. By introducing combinations of species and varieties, adjusting sowing dates and densities, as well as fertilisation, the competitiveness of the crop can be increased and conditions favouring the development of pests can be avoided.

The use of resistant **(3a)** and/or tolerant **(3b)** varieties makes it possible to prevent injury or to limit crop losses respectively.

Finally, when the levers employed earlier do not prove effective, **remedial solutions** (4) can limit injury (for example, using mechanical weeding as a remedial weeding measure). Chemical control also counts among such remedial solutions. The availability of remedial measures as a safety net makes it easier to introduce alternative strategies whose effects are sometimes partial. However, because of technical considerations, it is not always possible to have recourse to these solutions.

The methods on which control strategies less reliant on pesticides are based are illustrated in the following pages for the three categories of pests: disease pathogens, weeds and animal pests. What is presented here is a summary. For more details on the introduction of a particular practice, users can consult the sheets currently being created by the RMT SDCI. For more details on the introduction of a particular practise, users can consult the sheets **Agro-PEPS** currently being created by the Join Technology Network for « Innovative cropping system » available on http://agropeps.clermont.cemagref.fr/mw/index.php/Accueil.

It should be noted that the examples given here reflect the references currently available in mainland France for the introduction of alternative crop protection strategies. At the moment these references concern only a small number of crops, and the examples given are based on these. This section will be enriched as and when references become available for crops which have not yet been studied in detail.

III.2.1. Alternative control methods for weeds

The control methods are summarised in Figure 6, which details the effects of these methods on the pest cycle and crop status.

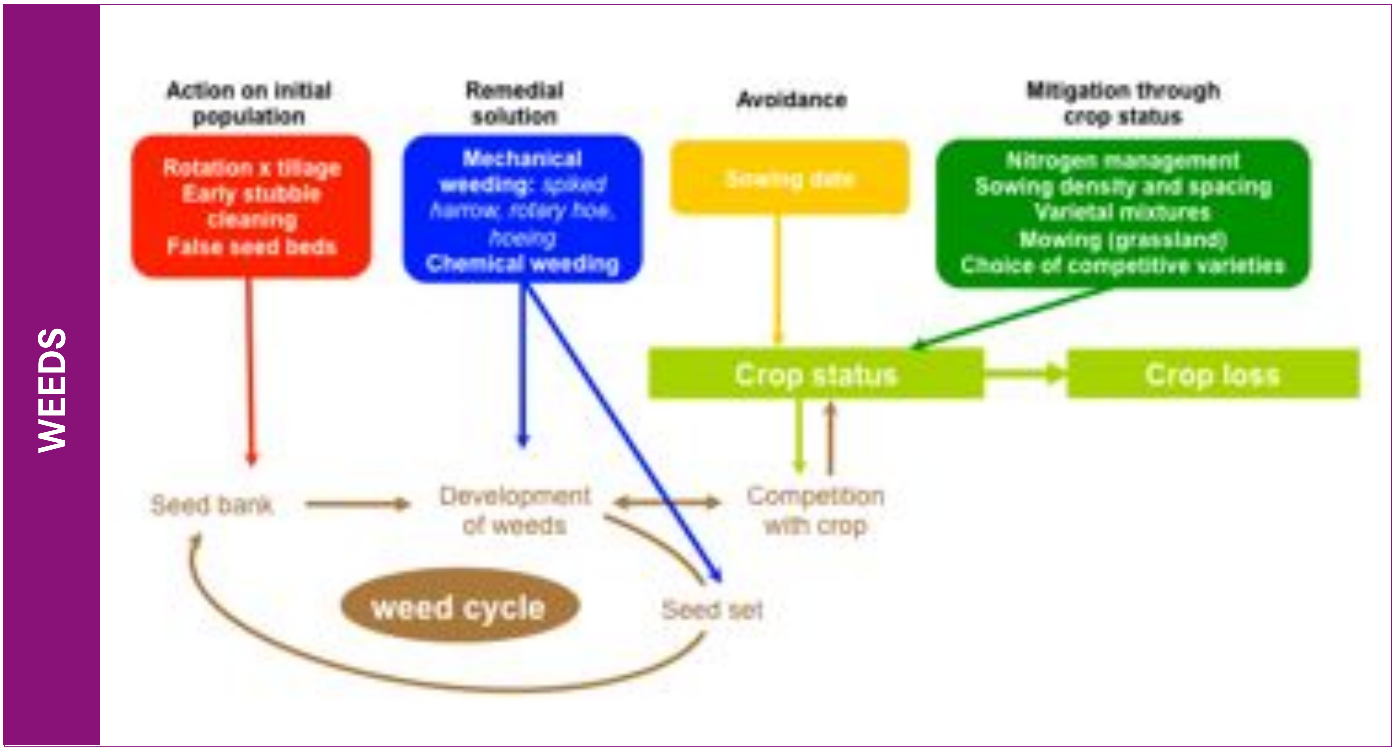


Figure 6 : Interactions between practices, crop status and pest cycle for weeds
Succession x tillage: this indicates that the crop sequence is planned in interaction with tillage to have the best possible control of weeds.

> **Farmer F1, who works in an integrated production system, says :**
> *«To control weeds, I introduce different families into my crop sequence, I alternate winter and spring crops, I use stale seed beds, I change my sowing dates and I use mechanical weeding: we have many options we can call on.»*

Alternative control methods often have a reduced efficacy against perennial weeds. In this section we concentrate above all on ways of managing annual weeds, while pointing out those control methods which could also impact perennial weeds.

Actions on the initial population: the seed bank

The development of annual weed species in a field strongly depends on its history and the persistence of weed seed in the soil. Contamination between fields is less important for weeds than for certain diseases or animal pests because seed dispersion is weak in the majority of species. However, tools used in the field can be a source of external contamination.
The choice of **crop sequence** is an important lever in controlling weeds. It makes it possible to diversify the season during which crops are established (autumn/spring/summer) to avoid specialisation of weed flora. Alternating cultivated species also results in a diversification of seed bed preparation (for example, differences in tillage depth), which reduces weed infestations [20]

Tillage makes it possible to bury weed seed. Ploughing under is most effective when it involves deep burying of weed seeds. For species with fragile seed (brome-grasses, foxtail, rye-grass, cleavers), a deep sojourn of more than a year can reduce their viability [21]. It can also lead to dormancy in persistent seeds. However, these may be brought back to the surface by subsequent ploughing. Therefore, it is useful to alternate deep and shallow tillage for effective management of these weeds.
Shallow tillage can destroy weeds in a physical manner (**early stubble cleaning or ploughing**) and stimulate their germination during the fallowg period to reduce infestations in the following crop (**stale or false seed beds**). This technique is effective for those species with weak dormancy that germinate in the upper few centimetres of the soil (brome-grasses, foxtail, rye-grass). However, one stale seed bed is rarely sufficient to reduce the seed bank by a satisfactory margin [22].
The presence of long fallow periods without a cover crop helps protect against weeds because it gives farmers the time to carry out field cultivation. A large number of passages through a field can maximise germination and ensure efficient destruction of seedlings. The final tillage before sowing should be as shallow as possible to avoid bringing up new seeds buried deeper in the soil. However, the effects of tillage are dependent on weather conditions and the characteristics of the flora. Above all, this lever is most efficient for autumn (cereals etc.) and summer (maize etc.) crops. It is not so easy to use for sowing in early spring.
In all cases, it is recommended that crops be planted in 'clean' fields to limit harvest damageg due to weed competition.

Regarding perennials :
Tillage also suppresses some weed populations, for example, dock (genus *Rumex*).
Species with shallow rhizomes, such as dog's-tooth grass, may be managed by tilling with toothed tools to uproot the rhizomes, which are then left to dry on the soil surface in sufficiently dry summer conditions (tools equipped with discs should be avoided as they break up the rhizomes and therefore multiply the weeds).

Avoidance strategies

Avoidance strategies[g] for weeds in autumn cereals are based on late sowing to avoid autumnal flora, which can be removed by preparatory tillage. This leaves only spring weeds to be managed. The crop canopy therefore needs to be well developed and competitive against these weeds. The avoidance effect is even greater when germination has been stimulated by stale seed beds during the fallow period.
This avoidance strategy can also be effective for crops sown at the end of the spring. Sowing beet or sunflower too early in spring can favour the emergence of weeds which tolerate lower temperatures [6]. In contrast, for crops sown at the start of the spring, weed emergence is staggered, which means that trying to avoid early cohorts by delaying sowing date is of only limited interest.
For smother crops whose standard sowing date is earlier than the usual germination period of weeds in the field (for example, oilseed rape), early sowing can reinforce the competitiveness of the crop because it will be stronger when the weeds germinate, provided there is adequate water and nitrogen for the crop.
Shifting sowing dates (sowing earlier or later according to the crop), while ensuring favourable sowing conditions, can therefore avoid exposing the crop to competition from weeds at the stage when it is most vulnerable.

Mitigation through crop status strategies[g]

For some cultivated species, increasing **sowing density** and reducing spacing between rows can reduce the growth of weeds and seed production by smothering them [23].

Weed populations can be controlled by introducing a **smother crop** into the crop sequence. Such crops have rapid growth, heavy branching, broad leaves and grow tall. To optimise the role they can play, it is preferable to use high sowing density and reduced spacing. The introduction of lucerne (alfalfa) or a temporary grass/forage crop makes it possible to interrupt the weed cycle before seed production, and to smother young seedlings by the rapid resumption of vegetation after mowing, assuming of course that the canopy has been successfully established [24].
The **management of nitrogen fertilisation** is also a lever, though its effects depend on the nitrogen needs of the crop and weeds. Oilseed rape, for example, is a highly nitrophilous crop that efficiently competes with weeds when nitrogen availability is high. In contrast, wheat is less nitrophilous than the majority of weed species and early nitrogen fertilisation will tend to favour weed growth.
Irrigation is another aspect to be adapted for avoiding the development of weed flora. For example, intensive irrigation in summer increases seed production of hygrophilous weeds such as Panicum grasses [25].
Finally, there are the options of **intercropping**[g], **undersowing/oversowing**[g], or the **combination of crops** used to cover inter-row spaces and consequently compete with weeds [26]. Combinations of **legumes and cereals**, for example, provide competition for light with weeds (the overall density of the cover is higher and the complementary architecture of the combined species makes for a more rapid canopy closure) and more efficient use of nitrogen, limiting the quantity available for weeds.
The **characteristics of the cultivated plant**, such as speed of emergence, vigour of the initial growth, speed and early production of seed, the horizontal arrangement of leaves and height, all influence the competitiveness of crops and therefore the control of weeds [28].
However, this lever is not always available at the present time because these criteria are not commonly used in plant breeding. For wheat, varietal differences in the ability to compete have begun to be characterised. For oilseed rape, certain hybrid varieties show an initial vigour which is greater than pure lines.

Regarding perennials :
For species with deep rhizomes (thistles), the introduction of temporary grass/forage crops, with a mowing regime preventing the growth of weed leaves above the canopy can be effective when associated with mechanical weeding.

Remedial solutions

Mechanical weeding (harrowing, hoeing or weeding) can destroy weed plants in the early stages of their development. Its primary role is to destroy newly emerged weeds while limiting the number of crop plants damaged by the operation [6].
It is relatively common to use mechanical weeding in species such as beet, maize and sunflower, but it is also possible in straw cereals and oilseed rape.
It can be used **on the crop** using a tine or spike harrow, a rotary hoe or a hoe equipped with flexible fingers. It can also be used **between rows** using a bladed, toothed or star-toothed hoe. Both weeds in the course of germination and emerging weeds are destroyed.
For robust or deeply sown crops, a passage with a spike harrow after sowing and before crop emergence can destroy very young weed seedlings, sometimes before emergence (‘white thread’ or cotyledonary stage), which contributes to limiting a potential infestation.
Remedial chemical control of weeds can also be used if necessary.

Regarding perennials :
For species with deep rhizomes (thistles), repeated hoeing of fields under cultivation, which tends to drain the plant of underground reserves, and passing over the field with very shallow duck foot tines during fallow periods can prove efficient.

Farmer F2, who is testing an integrated cropping system, says :
«I started using mechanical weeding this year. It is a practice requiring technical skills, and you need to find a balance between efficacy against weeds and selectivity for the crop. Above all, it works well on very young weeds. To adjust the equipment, I have used trial and error.»

III.2.2. Alternative control methods for pathogens responsible for diseases

The control methods are summarised in Figure 7, which details the effects of these methods on the pest cycle and on the crop status.

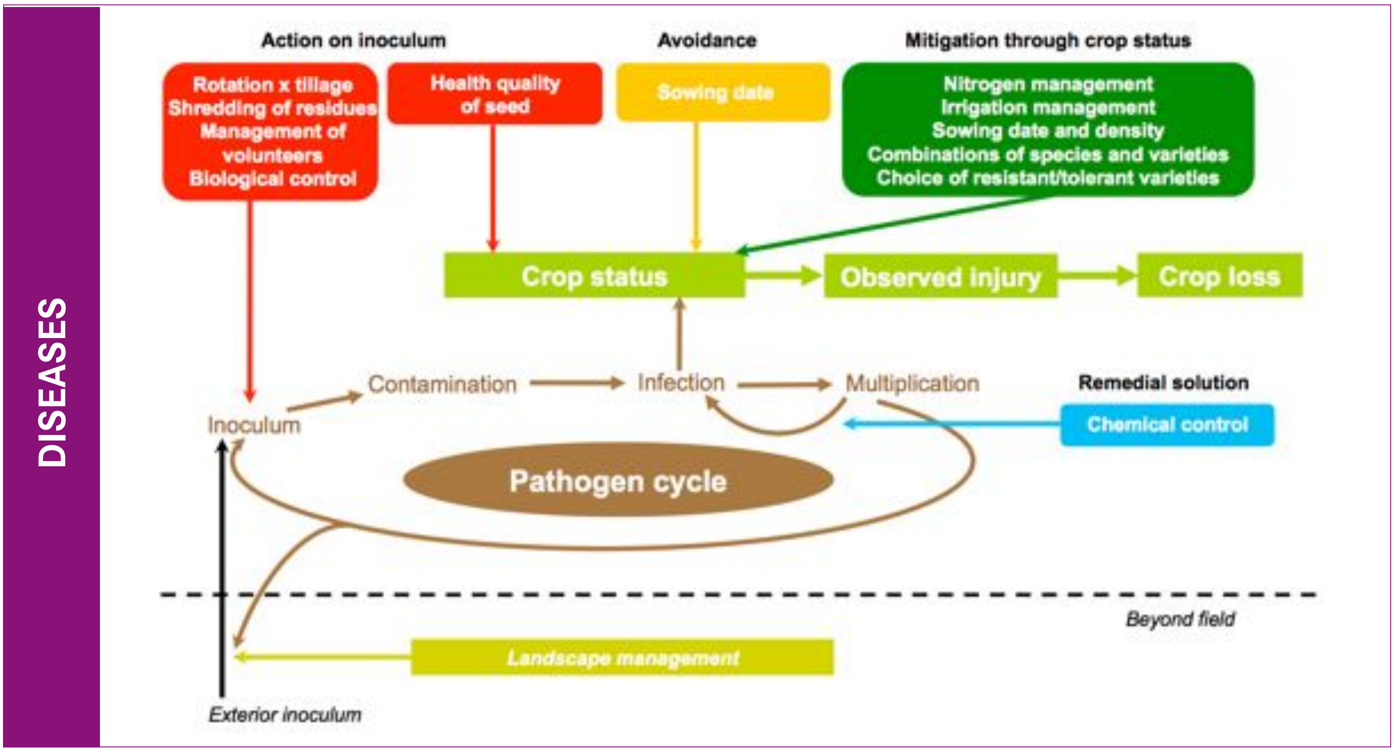


Figure 7 : Interactions between practices, crop status and pest cycle for pathogens responsible for diseases
Crop sequence x tillage: this indicates that the crop sequence is planned in interaction with tillage to have the best possible control of pathogenic agents.

Actions on the initial population : inoculum

Adaptation of the crop sequenceg is the principal prophylactic measure against diseases. Above all, it effects pest populations which dwell in the field, such as eyespot in cereals and root rot in peas [29]. It involves planning the time period before a crop returns to the same field and the preceding-crop effect of each crop, therefore alternating between host and non-host plants. If we take the example of common or bread wheat, the recommended time period is two or three years depending on weather conditions. It is therefore recommended that wheat be sown once every two years (or longer) while avoiding preceding crops which can harbour the same pathogens (for example, other cereals which can host Fusarium or eyespot).
When planning the rotation, we can also select crops suitable for **biofumigation**g. This involves growing a crop, chosen for its toxic potential against soil-borne pests, during the fallow period. The crop is then crushed and buried at a given stage. Suitable crops for this are generally cruciferous species such as mustard and radish. The effects of introducing brown mustard as a cover crop on Rhizoctonia have already been demonstrated [2].

A1, responsible for a watershed, says:
«Diversifying the crop sequence is not always possible: we have to find markets for those crops we want to introduce. New sales channels have to be developed.»

Particular attention must also be paid to the **sanitary quality of seeds** to ensure they are not a source of contamination. Attention must also be paid to the equipment used, as this can be a source of contamination between fields.
Management of the landscape around the field can limit contamination from pathogenic agents that can disperse (cf. p.39) to neighbouring fields. For example, we can avoid growing crops capable of hosting the same diseases in neighbouring fields.
Tillage is another important lever: it allows contaminated residues to be buried and therefore destroys inoculum[g] or limits air-borne spread (for example, straw of oilseed rape and sunflower crops contaminated by phoma [30]). Managing the burying of residues must take into account the inoculum's survival period as ploughing can bring infected residues to the surface in a host crop. The timing must therefore take into account the inoculum's survival period and the crop sequence.
This technique also affects soil conditions (lower moisture levels, changes in OM[a] level, changes in temperature and pH) which has consequences for soil micro-organisms and particularly on diseases, slowing their development.
However, the effects of tillage and its use are dependent on weather conditions in each particular location.
Shredding residues and burying them limits the retention of inoculum on the soil surface and accelerates the decomposition of residues, limiting the substrates available for saprotrophic fungi[g]. It is particularly recommended for slowly decomposing residues such as sunflower stalks, where shredding is used to control Phomopsis [29].
Destroying volunteers and weeds which host diseases is another method to control inoculum, notably biotrophic fungi[g] (for example, wheat rusts [29]).
Finally, biological control can be used to manage inoculum. An example is the use of Contans[1] on Sclerotinia.

Avoidance strategies[g]

Avoidance strategies consist of avoiding any concurrence between the phase when a pest can contaminate a crop and the period when the crop is susceptible. Thus the **early sowing** of oilseed rape can limit early phoma contamination in certain situations [31]. For spring peas, **late sowing** avoids anthracnose.
Similarly, the longer the vegetation period is, the more susceptible the crop is to pest attack as pests have time to develop. Early sowing of winter cereals therefore increases the risk of disease development because the pathogen can go through a larger number of cycles. Later sowing can limit the risk for a range of wheat diseases (septoria, rusts, take-all [29]). Opting for later sowing is accompanied by choosing varieties with a shorter cycle to maintain good production levels.

Farmer F2, who is testing an integrated cropping system, says :
«The practice of changing sowing dates requires good management of the risks: for the change to be really effective, sowing needs to be as late as possible. But the longer you wait, the more the weather conditions can make sowing difficult.»

Mitigation through crop status strategies[g]

Sowing density is a method for controlling disease propagation in a crop. The denser the sowing, the shorter the distance between two plants and this makes it easier for a pathogen to pass from plant to plant. Furthermore, dense sowing can lead to conditions favourable for disease development (lower light intensity, increased humidity). A reduction in sowing density of sunflower, for example, can reduce injury caused by Phomopsis [29].
In the case of oilseed rape, early sowing means that by September the crop canopy reaches a more advanced growth stage and is capable of better resisting disease injury, particularly from phoma. **Sowing dates** can therefore be used to ensure a disease's contamination period coincides with an advanced development stage in the plant, when it is better able to resist an attack.
Similarly, the **combination of species** in the same field can dilute the quantity of pathogenic agents present and form a physical barrier to disease propagation. This has been demonstrated for foliar diseases in wheat [32].
A **combination of varieties** can limit plant to plant propagation through using complementary resistance* and therefore reduce injury. In potato, for example, the severity[g] of mildew can be reduced by alternating susceptible and resistant varieties in the rows compared to a crop of a single variety [33].

[1]CONTANS® WG is a biological control product based on Coniothyrium minitans, a parasitic fungi which attacks the sclerotia (resting survival structures) of Sclerotinia species such as Sclerotinia sclerotiorum and Sclerotinia minor [4].*

Managing nitrogen availability can also be used to control diseases. For the majority of crops and diseases, high nitrogen availability during the crop's vegetative stage can lead to major growth in the leaf surfaces and increase the chances of contamination by spores. It also leads to changes in the microclimate which can encourage disease development. Finally, higher plant nitrogen levels can increase a crop's susceptibility to diseases [29].

Reducing nitrogen availability in wheat to control diseases has been successfully tested in France's 'hardy wheat' network.

Irrigation management should also be analysed to limit disease risk. In fact, the majority of operations designed to increase a field's productivity (including fertilisation and irrigation) encourage the creation of a microclimate favourable for the development of pathogens, notably by maintaining the humidity level below the crop cover. Phomopsis in sunflower [34] and smut in maize [22] can, for example, be encouraged by 'poor' management of water supplies in the field.

Choosing varieties which are resistant to diseases can reduce injury caused by foliar diseases. Several lines of resistant varieties have therefore been developed for the control of phoma in oilseed rape (varieties carrying the Rlm1, Rlm4 and more recently Rlm7 genes). However, using varieties with the same type of resistance on a large scale raises questions about the erosion of this resistance [22].

Choosing tolerant varieties can reduce harvest damageg caused by the same level of injury. Therefore wheat varieties offering different levels of toleranceg to septoria and eyespot have been developed [22].

In practice, the crucial criterion is the **susceptibility** of the variety.

In the case of septoria, the characteristics of the plant, such as the variety's precocity and the height of the stems, can ensure the highest leaves in the canopy are not affected.

Remedial solutions

Chemical control may be used as a remedial solution if the other levers have not been sufficiently effective and active ingredients are available for the disease in question.

Cartoon by Robert Rousso in Le Courrier de l'environnement from INRA n° 25, p. 29

III.2.3. Alternative control methods for animal pests

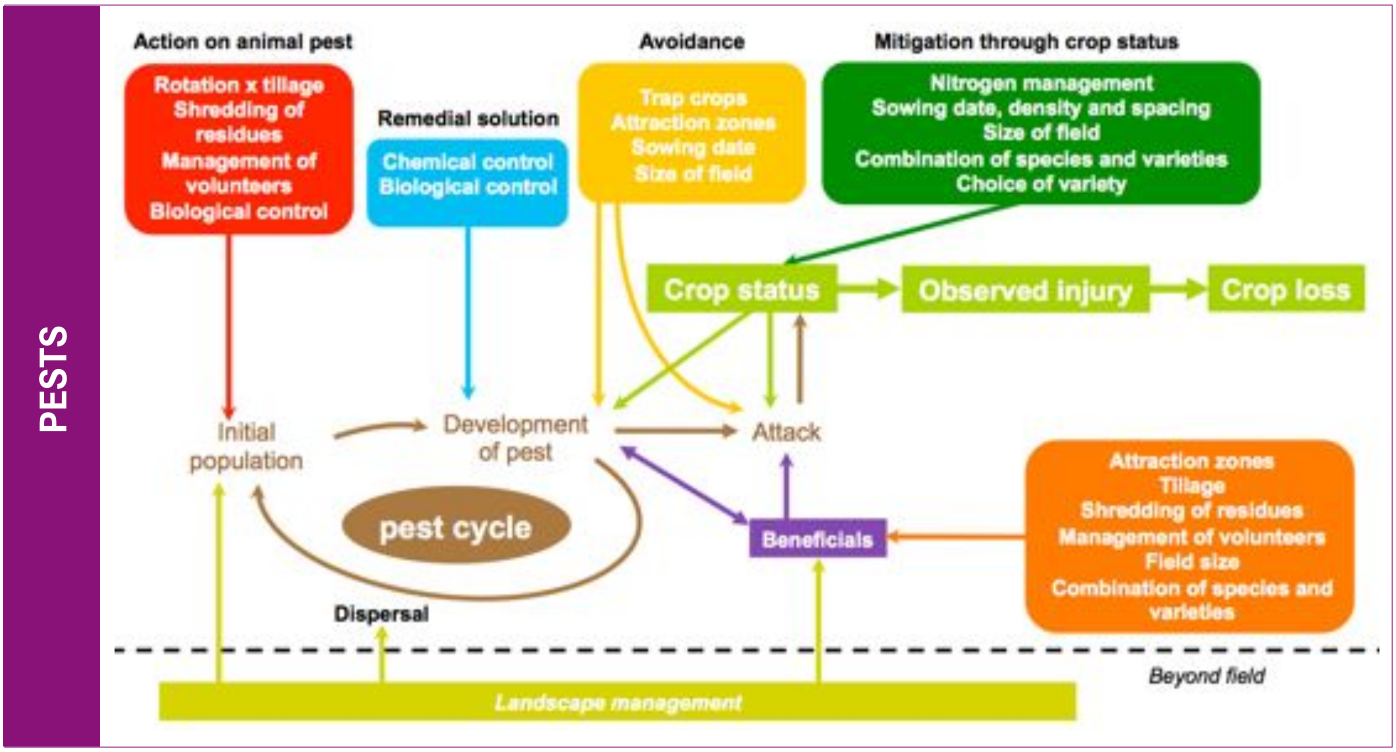


Figure 8 : Interactions between practices, crop status and pest cycle for animal pests
Crop sequence x tillage: this indicates that the crop sequence is planned in interaction with tillage to have the best possible control of animal pests.

Actions on the initial population

Alternating crops which are hosts and non-hosts to animal pests can limit the reproduction of organisms which are specific and endemic in the field. This is the case, for example, for nematodes in beet and oilseed rape. Lengthening the rotation is also the only efficient control method against western corn rootworm, whose potential to cause injury is strongly reduced by avoiding monocultures [35].
Tillage, whose effects vary according to the prevailing weather conditions, reduces pest populations found in crop residues (for example, stem weevils and pollen beetles in oilseed rape) and those found in soil (may bugs, Scutigerella etc. [22]) by killing larvae. The same result can be achieved by shredding crop residues, for example Lepidoptera such as European and Mediterranean corn borers etc. found on maize stems [22]. To reduce populations of soil insects such as wireworms and slugs, **stubble ploughing** in the fallow period[g] during dry weather can often be effective.
Many crop pests have natural enemies and appropriate **landscape management** can encourage their development. Introducing pest enemies is also possible and is used, for example, in the **biological control** of corn borers in maize through the introduction of *Trichogramma*.
However, tillage can also disturb the lifecycle of predators of certain pests (for example, beetles which feed on slugs).

Avoidance strategies[g]

In winter cereals, sowing too early increases the risk of attack from autumn insects (for example, aphids which are vectors for Barley Yellow Dwarf Virus). **Delaying the sowing date** allows the risk to be avoided though attention must be paid to ensure that conditions are suitable for sowing the crop [22].
Slow growth in plants increases the period during which they are susceptible to certain pests (wireworms, nematodes etc.). In spring crops (maize, beet, sunflower), delaying the sowing date increases the speed of growth and reduces the crop's exposure to pests. Late sowing deprives western corn rootworm larvae of the nutrition they require and therefore reduces injury caused by this pest [22].

Mitigation through crop status strategies[g]

Using a nitrogen-based starter fertiliser encourages early growth in crops and allows them to withstand attack by some pests (nematodes and soil insects). It also makes the plants more vigorous. Careful adjustment of **nitrogen-based fertilisation**, according to the production needs of the crop, limits the areas which are susceptible of being attractive to pests [36].
Taking the example of oilseed rape, early sowing allows the plant to reach a more advanced stage by September, when the weather turns wetter, and makes plants more resistant to slug injury.
High **sowing density** can limit harvest damage[g] and reduce injury per plant (the dilution effect). This has been proven for aphid injury in barley [37].
Finally, **combining species or varieties** can form a physical barrier to pest propagation in the field. It also acts by preventing pests from visually recognising the crop. Combining maize and peas, for example, reduces the number of pests for both crops [38]. Furthermore, combinations can encourage populations of natural enemies in the crops.
Growing **trap crops** around the edge of the field can also reduce pest populations in the field, attracting them away from the crop (cf. p.32).
Varieties which are **resistant** (by producing repellent substances, egg-laying inhibitors etc.) or **tolerant** can be used to limit pest injury and harvest damage. However, the availability of these varieties is variable at the moment and will depend on the crop in question.

Remedial solutions

Chemical control can be used as a remedial solution if the other levers have not been sufficiently effective and if appropriate active ingredients are available.
Similarly, biological control (for example, the use of Trichogramma on European corn borer) can also be used as a remedy.

A summary of the control methods for different categories of pests and their modes of action is provided in Table 2.

Table 2 : Summary of the effects of alternative control methods on pests [7]

Mode of action	Levers	Effects on diseases	Effects on weeds	Effects on animal pests
Action on initial population	Crop sequence	• Breaks disease cycle by alternating host and non-host plants • Biofumigation[g]	• 'Despecialisation' of flora through alternating sowing periods and planting methods • Suppression of weeds through the introduction of cover crops (for example, lucerne)	• Limiting reproduction of pests linked to soil
	Tillage	• Burying of infected residues, substrates of saprotrophic diseases[g] • Creation of a soil microclimate less favourable to diseases	• Burying and therefore non-germination of weed seeds • Destruction of weeds Germination of weeds through stale seed beds	• Interruption of the lifecycle of pests linked to soil or residues • Destruction of larvae
	Biological control	• Introduction of disease enemies		• Introduction of pest enemies
	Shredding of residues	• Destruction of substrate for saprotrophic fungi[g]	• Limiting seed production	• Destruction of larvae present in residues
	Management of volunteers	• Destruction of substrate for biotrophic fungi[g]		• Destruction of substrate for some animal pests
Avoidance	Sowing date	• Limiting number of disease cycles (late sowing) • Limiting periods when crop is susceptible (late sowing for winter crops, early for spring crops) • Plant is robust during the contamination phase of the disease (early sowing – oilseed rape)	• Competitive development of crop with weeds (early sowing for cover crops and weeds emerging after the habitual sowing date of the crops) • Avoiding weeds whose preferred growing periods are the habitual sowing dates for the crops (late sowing for autumn cereals)	• Avoiding attack periods (late sowing for winter cereals – autumn aphids; early sowing for rape – cabbage stem flea beetle)
	Trap crops			• Diversion of crop pests

<table>
<tr><th>Mode of action</th><th>Levers</th><th>Effects on diseases</th><th>Effects on weeds</th><th>Effects on animal pests</th></tr>
<tr><td rowspan="4">Mitigation through crop status</td><td>Fertilisation</td><td>• Limiting leaf surfaces available (rationing)
• Creation of a microclimate less favourable for diseases (rationing)</td><td>• Competitive development of nitrophilous crops with weeds, for example, oilseed rape (starter fertilisation)</td><td>• Development of more vigorous plants which are more resistant to pest attack (increased doses)
• Limiting leaf surface available to pests (rationing)</td></tr>
<tr><td>Sowing density, spacing between rows</td><td>• Limiting propagation of diseases (low density, wide spacing)
• Creation of a microclimate unfavourable for diseases (low density, wide spacing)</td><td>• Suppression of weeds (high density, close spacing)</td><td>• Limiting injury[g] caused per plant (low density, wide spacing)</td></tr>
<tr><td>Combination of species, varieties</td><td>• Complementarity of resistances[g] to disease in the crop
• Dilution of quantity of inoculum
• Creation of a physical barrier to the propagation of pathogens</td><td>• Increase in soil cover
• Increased efficiency in use of nitrogen available => increased competitiveness</td><td>• Physical barrier to pest propagation
• Less visual recognition of crop by pest
• Increase in number of natural enemies to pests</td></tr>
<tr><td>Choice of variety</td><td>• Resistance[g] of the crop to diseases
• Tolerance[g] of the crop to diseases</td><td>• Varieties competitive with weeds</td><td>• Resistance of the crop to pests
• Tolerance of the crop to pests</td></tr>
<tr><td rowspan="3">Remedial solution</td><td>Mechanical control</td><td rowspan="3" colspan="3">• Destruction of pest</td></tr>
<tr><td>Chemical control</td></tr>
<tr><td>Biological control</td></tr>
<tr><td colspan="2">Landscape management</td><td>• Limiting diffusion between fields</td><td></td><td>• Limiting diffusion between fields
• Management of natural enemies
• Creation of zones attractive or repellent to pests</td></tr>
</table>

Note: for simplicity's sake, this table does not take into account the interactions between the effects of different levers.

III. 3. Combining control methods to better meet farmers' objectives

Individually, each of these techniques is generally less effective than a chemical control programme: their effect is **partial**. A ranking of their efficacy has been compiled by the experts on the editing committee to help users and is presented in Table 3.

Principal levers are those which have an acceptable level of efficacy when used alone. **Secondary levers** are of low efficacy if used on their own and should therefore be combined. **Supplementary levers** make it possible to reduce injury or harvest damage* once pest populations are established, in other words they are remedial solutions[1].

This table is intended as a guide and therefore will not apply in every situation. The important thing is to remember that some practices are more effective than others, and that the **combination of different practices is the most effective mode of action for controlling pests.**

Table 3: Ranking of practices having an effect on pest control according to their efficacy

a. Efficacy of practices for diseases	
Principal levers	• Rotation • Choice of variety • Combinations of varieties, species
Secondary levers (to be combined)	• Sanitary quality of seeds • Tillage • Shredding of residues • Management of volunteers • Sowing date and density • Management of nitrogen availability
Supplementary levers	• Biological control • Chemical control
b. Efficacy of practices for weeds	
Principal levers	• Rotation (alternating sowing periods) • Tillage • Sowing date
Secondary levers (to be combined)	• Sanitary quality of seeds • Early ploughing (post-harvest) • Stale seed beds • Sowing density • Management of nitrogen availability • Choice of variety
Supplementary levers	• Mechanical weeding • Chemical control

[1]NB: This table does not take into account all the interactions which can exist: for example, management of animal pests can have an influence on management of diseases since some of the former are vectors for the latter. Similarly, management of weeds can have an effect on diseases and pests since weeds may be vectors for the same diseases as the crop and hosts of the same pests.

c. Efficacy of practices for animal pests	
Principal levers	• Rotation
Secondary levers (to be combined)	• Tillage • Shredding of residues • Management of volunteers • Ploughing (slugs) • Sowing date • Trap crops • Management of nitrogen availability • Combinations of species, varieties • Resistance/tolerance of variety
Supplementary levers	• Biological control • Chemical control

Limiting economic losses[g] engendered by pests therefore involves designing cropping systems which combine the techniques described above within alternative protection strategies. There is no single method which can be substituted for chemical control and, on its own, produce effective and sustainable control for crops. In fact, **generally all control methods exerting strong pressure on target populations gradually lose their efficacy as their use becomes more widespread**. This is the case, for example, for genetic control methods [21].
By combining different practices we can better manage the sustainability of control methods [21].
The same pest can be hit by different combinations of practices. Therefore different combinations of levers should be used to avoid the development of resistance to these methods and thus ensure their efficacy and sustainability. **Obviously, finding adequate combinations of practices for a given situation depends on farmers' objectives and the trade-offs to be made relative to the constraints**. For example, if the overriding objective is to reduce herbicide use to protect a water source, the systems selected may be very different to a situation in which this objective is coupled with constraints on maintaining soil structure, notably at the level of managing tilling practices. This is why **committing to a plan to reduce pesticide use is more than simply applying a set of pre-defined practices**; implementing all the practices described earlier does not constitute the optimal situation for crop protection. **Rather, it's about selecting the most effective and coherent practices, taking into account farmers' objectives and constraints. The programme described in the following pages of the guide allows this to be achieved.**

The efficacy of alternative solutions is dependent on prevailing weather and soil conditions. **The co-design of systems adapted to the local environment with farmers**, who are best placed to supply details of this environment, therefore appears to be **essential in obtaining an appropriate alternative crop protection strategy.**

To help users in their consideration of combinations of practices, Table 4 sets out examples tested in several experimental networks. Once again, it is based on just a few examples.

In addition, Annex 2 of the guide outlines some 'typical' crop management plans by crop and according to different protection rationales. This can help inspire us in the design of cropping systems less reliant on pesticides. Of course, it's not about ready-made 'recipes'; these CMP[a] must be adapted to the situations in which they are used.

Table 4 : Combinaisons of actions known to have an effect on pests

	Actions on initial pest populations	Actions on crop status	Actions on initial pest population and on crop status
Weeds	▸ Diversification of crops in the rotation x adaptation of tillage for the rotation and the biology of weeds for control of weeds in wheat	▸ Choice of competitive varieties + early sowing + increase in sowing density + increase in available nitrogen for the crop for control of weeds in rape ▸ Choice of competitive varieties + dense sowing + mechanical weeding for control of weeds in spring barley ▸ Stale seed beds + late sowing + choice of competitive varieties + hoeing for the control of weeds in spring crops (maize, beet, sunflower)	▸ Diversification of crops in the rotation x adaptation of tillage for the rotation and the biology of weeds + choice of competitive varieties + late sowing + increase in sowing density (CMP 'integrated wheat' for the control of weeds) ▸ Diversification of crops in the rotation + introduction of cover crops + stale seed beds + later sowing + mechanical weeding for control of weeds in cropping systems with resistance to herbicides problems
Diseases	▸ Lengthening of rotation with a reduction in the frequency of the return of straw cereals + suppression of wheat volunteers for control of eyespot in wheat ▸ Lengthening of rotation with a reduction in the frequency of the return of straw cereals x adaptation of tillage for the rotation for control of take-all or Fusarium in wheat	▸ Choice of hardy varieties or combinations of varieties + late sowing + reduction in sowing density + reduction in nitrogen inputs for control of foliar diseases in wheat ▸ Choice of varieties less susceptible + early sowing + reduction in sowing density + reduction in nitrogen inputs for control of Phoma in oilseed rape	▸ Lengthening of rotation with a reduction in the frequency of the return of straw cereals x adaptation of tillage for the rotation + late sowing + reduction in sowing density (CMP 'integrated wheat' for the control of diseases)
Animal pests		▸ Choice of 'robust' varieties + early sowing + reduction in sowing density + adjustment of nitrogen fertilisation according to the needs of the crop (for example, insects in rape)	▸ Lengthening of rotation with a reduction in the frequency of the return of straw cereals x adaptation of tillage for the rotation + late sowing + reduction in sowing density (CMP 'integrated wheat' for the control of animal pests) ▸ Lengthening of rotation with a reduction in the frequency of the return of maize x tillage (stubble ploughing, tilling) + advancing of harvest date + shredding of canes for the control of European corn borers and other boring insects in maize

x: inseparable practices – strong interactions *+: practices to be combined – weaker interactions*

'Alternative' practices do not only influence the targeted pest. **The same practice can have consequences on different pests**. These practices therefore have the advantage of generally being more **versatile** than plant protection products, insofar as the latter are often specific to a pest or a given type of pest. Crop sequence combined with tillage is, for example, an important lever for the control of three categories of pests (weeds, diseases and animal pests). On the other hand, **there can be some antagonism between the effects of these practices on different pests.** Some examples are shown in Table 5.

Table 5: Examples of antagonistic effects of practices on different pests

Practices	Pests controlled	Negative effects on the control of other pests
Increase in sowing density	Weeds	Favours the development of fungal diseases
Increasing N[a] levels in the soil (for nitrophilous crops such as oilseed rape)	Weeds with lower nitrogen needs	Favours the development of nitrophilous weeds Favours the development of fungal diseases
Burying crop residues (ploughing)	Diseases	Disrupts the cycle of beneficials => reduces their effect on pests
Combination of species	Diseases	Can increase harvest damage* caused by pests through its concentrating effect
Sowing of some cover crops in fallow period	Nematodes	Slug injury Can favour the development of some diseases

Cropping practices do not only influence pests; **they have effects on other elements in the agro-ecosystem**. For example, tillage has an effect on soil structure. These 'secondary effects' have not been listed here, but are described in the RMT SDCI[a] practical sheets.

Summary of the first section :

- While alternative crop protection measures exist, there is no method which, used solely, has the same efficacy as that of a plant protection product. Developing a crop protection strategy less reliant on pesticides involves **combining several control methods with partial efficacy which act on the development of injury to limit economic losses[g] due to pests**, and possibly tolerating damage and crop losses if they don't generate economic losses.

- A reduction in the use of plant protection products involves **modifying existing cropping systems for the implementation of prophylactic measures and, possibly, remedial measures.**

A1, responsible for a watershed, says :
«The system needs to be built bit by bit, adapting the farm as a whole. It does not mean just deciding if we use fewer inputs on a given field: that might work for one year, but not all the time.»

In this section, only those actions working at the field scale have been described. **However, acting beyond this scale is equally important in the control of pests.** The box on page 37 provides the elements to be considered when acting at a scale above that of the field.

What follows is our suggested programme for the design, with farmers, of alternative cropping systems that enable crop protection strategies less reliant on pesticides. It allows us to consider these alternative systems taking into account the context (agronomic, socio-economic and environmental) in which the current cropping system exists.

Cartoon by Robert Rousso in Le Courrier de l'environnement from INRA n° 36

Actions above the field scale for reducing the use of plant protection products

Acting above the field scale provides access to supplementary levers for controlling mobile pests[g]. In fact, these actions can boost the efficacy of practices introduced at the field scale by limiting contamination from pests arriving from beyond the field. Furthermore, they contribute to the preservation of beneficialsg which help control pests. Finally, they make it possible to ensure the sustainability of the protection methods used through their judicious division over the landscape.

→ Actions at the farm scale

▸ Management of fields and crops[g] [38]

Reasonable field sizes can ensure better management of pest populations. A compromise between optimising mechanical work and maintaining the variety of species over the landscape creates zones favourable for the biodiversity of fauna, and can therefore be the source of beneficials to regulate pest populations. From an operational point of view, a good limit would be the maximum area which can be sown in eight to 10 hours of work. Using this rationale, we arrive at fields between five and 15 hectares in size. It could equally be argued that the size of fields should be according to their 'natural' limits and therefore we could seek to have homogenous soils in each field. This also makes it possible to better manage inputs (water, nitrogen) in each field.
The spatial positioning of crops is equally important: avoiding a juxtaposition of crops which are host to the same pathogen limits contamination between fields. The propagation of numerous diseases and parasites can be slowed by the judicious partition of crops over the space available.
Furthermore, the arrangement of different crops can act as a brake on erosion in the absence of other landscape measures.

▸ Landscape management [17]

Field surroundings also have an important role in pest management. Non-cultivated zones (grass or flower strips, hedgerows, ponds etc.) harbour useful species (beneficials), which help control crop pest populations. The presence of flowers throughout the year offers a home to larvae which feed on aphids. Similarly, the maintenance of ponds offers accommodation to amphibians which feed on slugs. These species are often destroyed in the field, through both cropping techniques and the use of pesticides, and non-cultivated zones offer a source for the recolonisation of the field.
Refuge strips which are not treated with chemicals can also be created inside the field for preserving beneficial populations. Strips 2m wide every 70 m can, for example, maintain beetle populations for managing slugs.
Arrangements such as these increase the heterogeneity of the landscape and this can slow the progression of diseases disseminated by the wind or through other pests.
Of course, hedgerows and grass strips bring other advantages too: combatting erosion, limiting pollution of watercourses by nitrates or plant protection products, and can play an economic and landscape role etc.

→ Collective actions at local community and landscape level [17] [39]

Concerted and collective actions can also be taken at the local community level. Thus, the campaign against European and Mediterranean corn borers is currently being tackled collectively in some maize production areas. Likewise, the use of Contans against sclerotinia could be used at a collective scale for affected crops (sunflower, pea and oilseed rape).
Equally, the creation of crop 'mosaics' at a local landscape level can slow the progression of pests. This could play an important role in limiting erosion of resistanceg by creating mosaics of crops using varieties with different modes of resistance.
'Push-pull[g]' strategiesg can also be used at the community level to create zones which repel and zones which trap pests in a judicious manner in relation to the location of crops.

For more information :

• Follow links for agriculture/paysage :
http://www.agriculture-et-paysage.fr

• On biodiversity in farms :
http://www.hommes-et-territoires.asso.fr, work conducted by the IBIS[a] project

PART II: A METHOD FOR CO-DESIGNING CROPPING SYSTEMS LESS RELIANT ON PESTICIDES

I. THE ROLES OF FARMERS AND ADVISERS IN THE DESIGN OF NEW CROPPING SYSTEMS

During the design of innovative cropping systems, **the role of agricultural advisers is significantly different** to the role they currently fill. Until now in France there has been a rather top-down approach, with advisers providing farmers with information and knowledge from research and development. Today the role has changed, notably when we don't have all the information on so-called 'innovative' systems. Furthermore, farmer groups, members of the SAN, OF and CT networks[a], faced with gaps in institutional advice, have developed their own expertise in farming with fewer inputs.

Therefore, the adviser's role is rather more **pedagogical and a support** to the farmer, where he offers methods for innovation and tests practices because he does not have the answers. Equally, he can gather and disseminate the results of innovation initiated by farmers.

On the farmer's side, the change in practices involves changing some benchmarks. The idea of a 'clean field' needs to be revisited: a field can house species other than the crop species without it affecting the crop. In some cases, farmers will have to reduce their yield objectives, while bearing in mind that revenues will not necessarily be lower. We therefore need to address economic margins rather than gross yields [40] [41] [45].

Farmers F1, F2 and F5 say :
«We always compare yields, and not margins. It is difficult to consider margins because farmers in general don't like to talk about their income.»
«My yields are between 10 and 20% below the average yields for the region. But for wheat, for example, I have a €300 difference in the average production cost. Therefore my margins have remained the same.»
«We have to accept that we need to consider the crop sequence and relearn how to manage our budgets at that level, and not at the level of the crop.»

Along the same lines, farmers need to think at the rotation scale rather than the growing year: the introduction of a crop such as peas between two wheat crops can, for example, be met with some scepticism because it produces a lower margin than wheat. However, if we consider the nitrogen it brings into the system and the fact that it breaks the parasite cycle, reducing applications of plant protection products, its introduction can improve the margin for the wheat crop which follows. The calculation of margins should be optimised at the rotation scale and not at the scale of the cropping pattern as is generally the case.

Finally, **changing the cropping system involves some 'risk' which farmers should be prepared to accept**: while the introduction of preventive measures diminishes the risks linked to pests, the lack of decision support tools means there is no way of determining if we should intervene or not. This has to be judged according to observation, and this can appear less reassuring to farmers.

Therefore, farmers must be conscious of both the advantages and the limits of the change. They must be clear about what they want to improve: Increased efficiency in the use of pesticides? Reduced use of these products? Improved control of pests[g]? They need to be prepared in the medium to long-term to encounter losses to achieve this (in terms of yields, investing additional hours of labour, etc.).

Farmers F1, F2 and F6 consider risk management and labour needs in integrated systems :
«We do not take risks blindly: we consider them in terms of thresholds. We will count numbers of weeds, and we will manage them over the crop succession rather than in a given year: we know we can use the following crops to destroy weeds. For aphids, we observe the ladybird populations: if these are large then the use of insecticides is potentially unnecessary. And furthermore, we are not organic: if there is really a worry, we allow ourselves to resort to the chemical option.»
«I do not have lots of time to dedicate to crops because of my livestock operation: my system allows me to reduce the operations conducted in the crops, notably in reducing the number of sprays. Diversifying the crops changes the sowing dates, which means the work is not spread out in the same way over the course of the year.»
«The time spent conducting observation in the crops is not necessarily longer in an integrated system, it is the time in taking decisions that is longer: we pose more questions before deciding to act.»

II. THE SUGGESTED APPROACH [42] [43]

The approach adopted in this guide for constructing cropping systems less reliant on pesticides is illustrated in Figure 9.

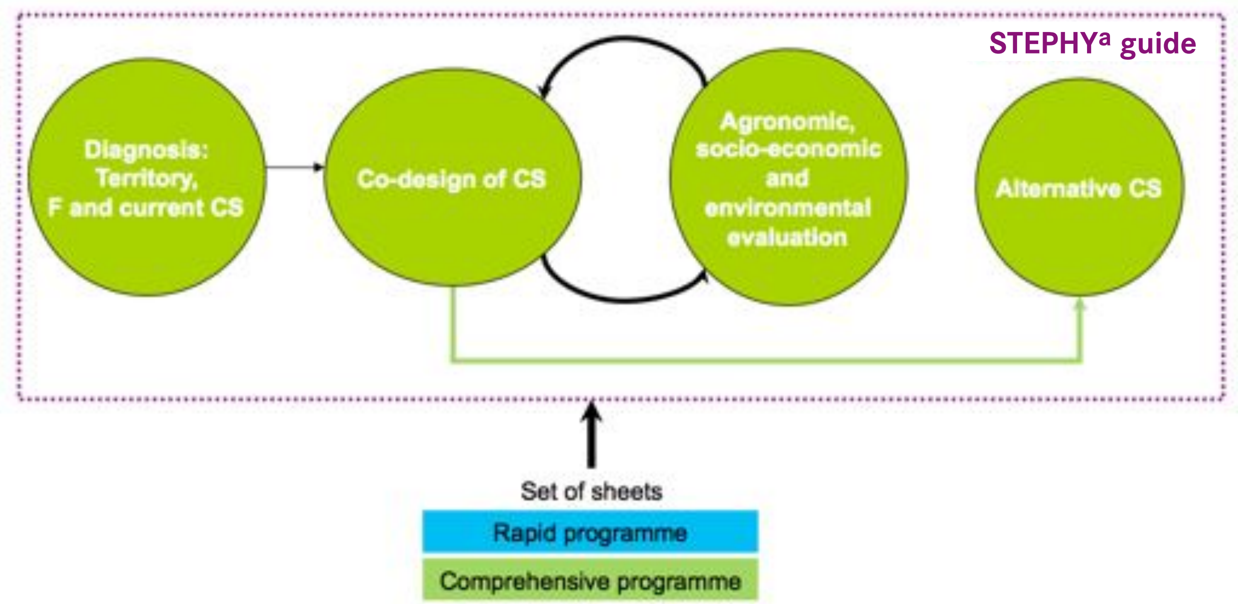


Figure 9: The approach used in this guide for designing cropping systems

PART II: A METHOD FOR CO-DESIGNING CROPPING SYSTEMS LESS RELIANT ON PESTICIDES

The process laid out here is based on an understanding of the agronomic, environmental and socio-economic context in which a farmer's current cropping system is situated. It generates several possible alternative systems which take into account the means and constraints of the farmer. We therefore work on one cropping system at a time rather than the entire farm. This approach is associated with an evaluation of current and alternative systems based not only on environmental criteria (level of pesticide use, nitrogen balance and energy consumed) but also on economic criteria (direct margin) and social criteria (number of interventions). Annex 1 of the guide provides a list of the indicators used for this step of the evaluation.

The suggested steps for the construction process are the following :

1. *Diagnosis of the initial situation and description of CS[a] to be improved*
   - Overall functioning of the F[a]
   - Description of the CS[a] to be improved
   - Evaluation of current CS[a]
2. *Co-design of alternative cropping systems*
   - Consideration of the rotation
   - Consideration of the crop management plans
3. *Evaluation of alternative cropping systems compared to current CS[a].*
4. *Discussion of the results.*

At each step of the programme, '**support sheets**' can be consulted and '**help sheets**', containing useful information for the design, are also available. The sheets are designed as an aid that users can modify for their own use.
A calculator is also offered with the guide and can be used to evaluate the CS[a] based on several indicators: TFI, nitrogen balance, energy efficiency, direct margin, number of interventions etc. It is designed to rapidly provide the performance indicators of the existing and alternative CSs[a]. **However its use, while recommended to help objectify discussions between advisers and farmers, is not essential at the design stage**.

In this guide, we describe the complete programme for farmers and advisers to co-design cropping systems less reliant on pesticides.
We are nevertheless aware that the implementation of the entire programme is not always possible due to restraints on time, on the means available or the involvement of farmers in the programme. For the essential steps of the programme we therefore offer two options:

- A **'comprehensive' programme**, offering the complete package.
- A **'rapid' programme**, offering a simplified version. It should be borne in mind that this programme is less precise in some aspects, notably for the evaluation of current and alternative cropping systems.

At each step, users can choose between the two programmes depending on the time they have available and the precision they want to achieve. Users could choose to use the rapid programme in the first instance and return to the farm a second time to conduct more detailed work.

For easier use of the support sheets, they are divided into the two types of programme. Two 'books' therefore accompany the guide, corresponding to the two programmes offered.

The programme, alongside the points in common and differences between the comprehensive and rapid versions, are summarised in Table 6.

Throughout this section of the guide, the example of the same farm is used to illustrate how the programme proceeds and how the support sheets can be consulted.

PART II: A METHOD FOR CO-DESIGNING CROPPING SYSTEMS LESS RELIANT ON PESTICIDES

Table 6: Summary of different courses and steps of the suggested programme

Step 1 : Diagnosis of the initial situation

1.a. Overall performance of the farm

Objectives :

- Understanding the overall objectives of the farmer for his farm
- Understanding the assets and constraints of the farm
- Identifying the CS[a] of the farm and which should be improved first

Rapid programme	Comprehensive programme
Undertake a diagnosis of the farm	Undertake a diagnosis of the farm

1.b. Description of the cropping system to be improved

Objectives :

- Characterise the CS[a] (crop sequence, CMPs[a]) and soil types
- Become acquainted with the farmer's objectives and issues with this CS

Rapid programme	Comprehensive programme
Description of the crop sequence Rapid description of the CMPs + more detailed description of CMPs for one or two crops	Description of the crop sequence Description of the CMP[a] for all crops in the rotation

1.c. Evaluation of the initial system

Objectives :

- Evaluate the CSa based on a list of pre-established indicators, making it possible to later compare the performance of these to proposed alternative systems

Rapid programme	Comprehensive programme
Rapid characterisation of CS[a]	Multi-criteria evaluation of current CS[a] using the STEPHY[a] calculator

Step 2: Co-design of alternative cropping systems

Objectives :

- Identify with the farmer those agronomic levers already used in the current CS[a] at the rotation scale
- Identify supplementary levers which could be interesting to use, according to the objectives

2.a. Considering the rotation

Rapid programme	Comprehensive programme
Identify those levers used at the rotation scale in the current CS[a] Suggest supplementary levers for implementation	Evaluation of the implementation of the levers available at the rotation scale on the current CS[a] Suggest supplementary levers for implementation

2.b. Considering the CMP

Rapid programme
Identification of levers for implementation at the CMP[a] scale in the current CS[a]
Suggest supplementary levers for implementation
Rapid description of new CS[a] constructed

Comprehensive programme
Identification and understanding of the modes of action of levers for introduction at the CMP[a] scale for the current CS[a]
Suggest supplementary levers for implementation based on the characterisation of principal pests
Description of CMP[a] for crops in the new CS[a] agreed upon

Step 3: Evaluating alternative cropping systems compared with the initial cropping system

Objectives :
- Evaluate the performances of alternative CS[a] compared to the initial CS[a]

Rapid programme
Qualitative evaluation of the performances of constructed CS compared to the farmer's current CS[a] according to selected indicators

Comprehensive programme
Multi-criteria and quantitative evaluation of the performances of the constructed CS[a] compared to the farmer's current CS[a]
Simulation of the evolution in performances according to variations in yields or different price contexts

Step 4: Discussion of results

Objectives :
- Discuss the introduction of alternative systems suggested for the farm

III. STEP 1 : DIAGNOSIS OF THE INITIAL SITUATION

III.1. Overall performance of the farm

Objectives :
- Understanding the farmer's overall objectives for the farm
- Understanding the farm's assets and constraints
- Identifying the farm's CS and which should be improved first

Help available :

Rapid programme
- Support sheet S1: Summary diagram for the diagnosis of the farm
- Help sheet H1: Questionnaire for the diagnosis of the farm

Comprehensive programme
- Support sheet S1: Summary diagram for the diagnosis of the farm
- Help sheet H1: Questionnaire for the diagnosis of the farm

Note: ***The diagnosis of the initial situation can be completed beforehand by advisers working alone if they already know the farm and have the appropriate information at hand (characteristics of the farm****, cropping systems present and the farmer's practices). These can then be rapidly discussed and verified with the farmer before moving to step 2.*

In this step, there is no difference between the two programmes offered.
In this step, the farmer should be questioned in order to **understand the farm's overall performance. The main barriers and constraints** affecting the farmer should be identified, alongside the **assets available** for modifying the system. To help produce the diagnosis, a list of questions is provided in help sheet H1. This list provides information for support sheet S1, which summarises the different aspects of the farm, identifying the most widely used cropping systems and the reasons for the farmer's choices. The information to be entered in the appropriate boxes is not a complete description but those points which could have an important influence for the cropping system to be improved. This helps **identify the choices and compromises to be dealt with in the construction of alternative cropping systems.**
It is therefore necessary to objectify what the farmer says with the help of the adviser's personal references and knowledge of the local context. For example, a farmer may consider the presence of a pest to be a major constraint even when its presence is infrequent and it does not lead to major economic losses[g]. To elucidate on this, it is useful to take into account the farmer's counts and observations, alongside local observation networks. Through the farmer, we can estimate the incidence[g] and severity[g] of injury caused by the pests present, and compare this with the average pest presence in the region.
We therefore arrive at an **assessment of the main problems the farmer is facing, what he is willing to change to resolve them and those things he does not want to change.**
This document should be considered a basis for discussion and not act as a block to possible changes in practices. For example, organising the work could be considered a major constraint on the farm, but this can be discussed. This should be done in those cases where propositions are likely to act as a lever to constraints identified by the farmer and to provide improvements to the cropping system.
At the end of this step, working with the farmer we choose one or several CS[a] to be improved and identify the reasons why the farmer would like to work on these systems. These cropping systems are then studied one by one. Figure 10 shows how the information is recorded in support sheet S1.

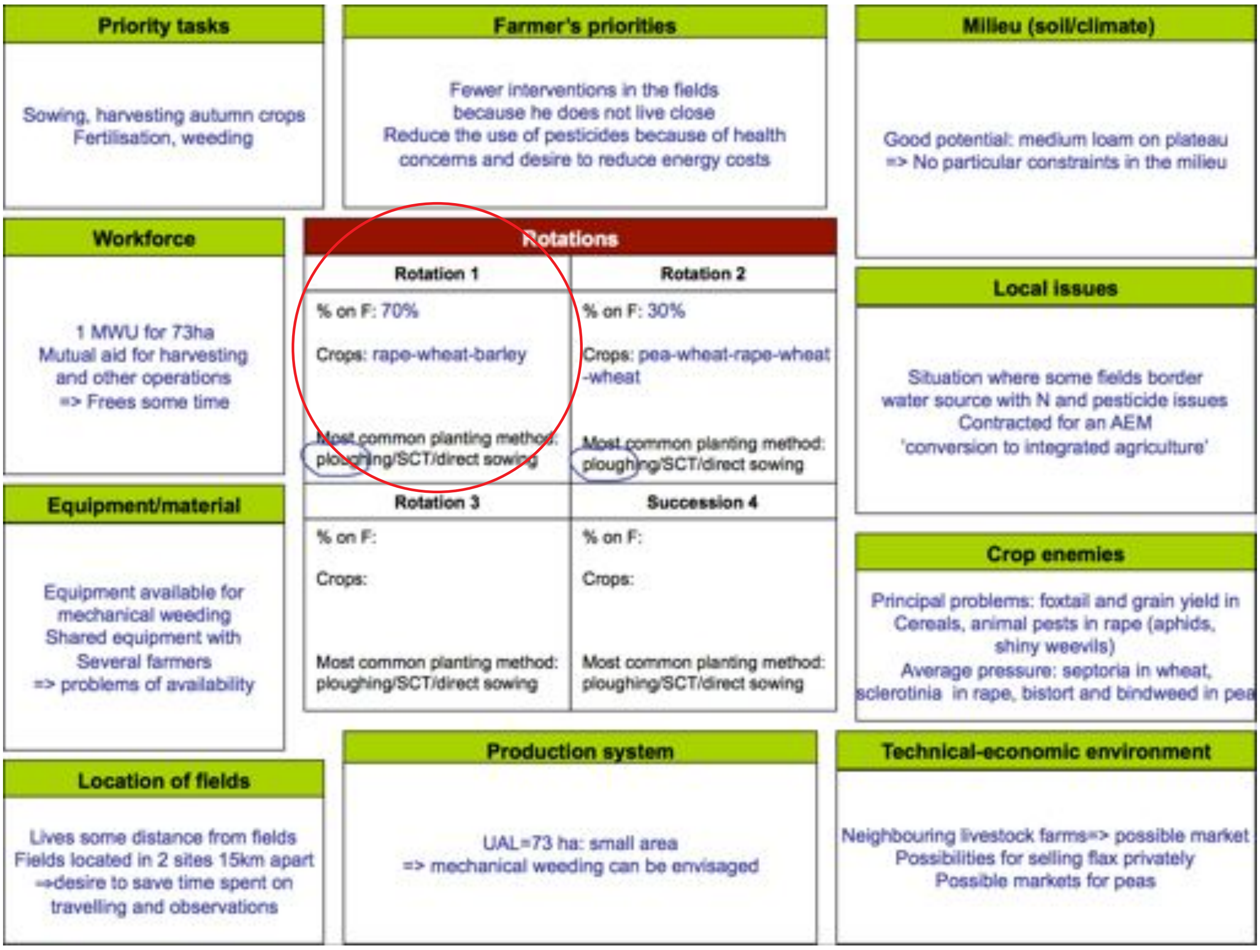


Figure 10: Example of the information recorded on a diagnostic sheet for the farm

III. 2. Description of the cropping system to be improved

Objectives :

- Characterise the CS[g] (crop sequence, CMPs[g]) and soil types
- Become acquainted with the farmer's objectives and issues with this CS[g]

Help available :

Rapid programme

- Support sheet S2A and B: Description of CS[g]
- Help sheet H2: Examples of possible objectives and constraints in a CS[g]

Comprehensive programme

- STEPHY[a] calculator – description sheet of the crop sequence (cf. support sheet S2 for the model)
- Help sheet H2: Examples of possible objectives and constraints in a CS[g]

Note : if the farmer's practices have already been recorded elsewhere, they can be put to good use here and be used as a basis for discussion.

At this stage, the first task is to **describe the crop sequence** and to **understand the farmer's objectives and choice of crops**. It is particularly useful to identify the level of injury[g] (total absence of pests? Limited injury and at what level? What intervention thresholds are used?) and harvest damage[g] the farmer is prepared to tolerate for a given revenue (to what potential level of yield lossg is the farmer prepared to go?). It is important to evaluate here what the farmer wishes to change, what he wishes to conserve and for what reasons.
For the second task, **the CMP[a] is described for each crop in the crop sequence**. This makes it possible to **determine the farmer's crop protection strategy** (systematic protection/supervised/alternative/integrated production[g] – cf. Figure 11), and therefore estimate the room for manoeuvre available for constructing a cropping system less reliant on pesticides. **For this, it is interesting to describe the variability in the methods used for the same crop**. For example, if all wheat is grown in an identical manner, even if the preceding conditions have been different or the fields in which they are grown are different, this translates into a 'systematic' crop protection strategy where treatments are identical for the same crop. If the CMP[a] changes as a result of the characteristics of the field and preceding conditions for the crop, this indicates an integrated crop management strategy, even an integrated production strategy.

Rapid programme

For this programme, we suggest that only the method used for producing one or two principal crops is described in detail (for example, wheat at the head of the rotation) in order to rapidly determine the farmer's protection strategy. Support sheet S2A can be used to record this description. The methods for other crops are then evaluated more rapidly, using criteria such as tillage during the fallow period, date and density of sowing, choice of variety, total nitrogen dose given and, finally, average production yields and their variability. These criteria should be used according to their pertinence for the crop in question. Support sheet S2B can be used to record this simplified description of the cropping system, with the help of help sheet H2 for identifying the farmer's objectives and constraints. The example presented in Figure 11 gives an example of how to use these sheets.
While this description makes it possible to rapidly determine the farmer's strategy, it is insufficient for studying in detail crop management plans for crops other than the principal ones and in producing a complete evaluation of the current cropping system.

Example

	Principal crop 1		Principal crop 2	
CROP	Oilseed rape (head of the rotation)		Winter wheat	
MANAGEMENT	'Typical' management	Variability in practices and causes	'Typical' management	Variability in practices and causes
MANAGEMENT OF FALLOW PERIOD				
Shredding of residues (yes/no)	Yes		Yes	
Chemical weeding				
TFI or costs (€/£)	1 glyphosate			
TIllage				
Ploughing (yes/no)	Yes		Yes	
Superficial cultivation (type and number of passages)			2 ploughing	
Sowing of intermediate crop				
Species sown				
SOWING				
Sowing date (early/average/late)	Average		Average	
Number of varieties	1		1	
Type of varieties (susceptible/low susceptibility)	Low susceptibility to phoma		Low susceptibility to foliar diseases	
Sowing density (low/average/high)	Average		Average	
Spacing of rows (narrow/average/wide)	Average		17 cm	
Seed treatment (yes/no)	Yes		Yes	

	Principal crop 1		Principal crop 2	
CROP	Oilseed rape (head of the rotation)		Winter wheat	
MANAGEMENT	'Typical' management	Variability in practices and causes	'Typical' management	Variability in practices and causes
FERTILISATION				
Mineral fertilisation				
Mineral nitrogen inputs (kg of nitrogen/ha)	170		180	
Number of inputs	2		3	
Organic fertilisation				
Organic fertilisation	0		0	
Organic nitrogen inputs (kg of nitrogen/ha)	-		-	
CROP PROTECTION				
Herbicides				
TFI/costs (€/£) or number of passages	3 herbicides TFI = 2.2		2 herbicides TFI = 1.8	
Fungicides				
TFI/costs (€/£) or number of passages	1 fungicide TFI = 1		2 fungicides TFI = 1.6	
Insecticides				
TFI/costs (€/£) or number of passages	6 insecticides TFI = 3		1 insecticide TFI = 1	
Others (molluscicides, regulators, etc.)				
TFI/costs (€/£) or number of passages	1 regulator TFI = 0.6		1 molluscicide TFI = 0.9	0 to 1 intervention depending on observations
Mechanical control				
Hoe/harrow/rotary hoe – number of passages	0			
Biological control				
Control method (Trichogramma, Contans etc.)	-		-	
IRRIGATION				
Quantity of water added (m3/ha)	-		-	
HARVEST				
Yield (q/ha)	35		80	65 to 85

Farmer's objectives and constraints :

Improving management of graminaceae (ray-grass and blackgrass) in cereals
Improving management of animal pests (aphids and blossom beetle) in oilseed rape
Eventually reducing labour time

Current CS	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
CROP	Oilseed rape	Winter wheat	Winter barley			
Ploughing (yes/no)	Yes	Yes	Yes			
Tillage during fallow period (number of passages)	2	2	2			
Sowing date (early/average/late) and density (low/average/high)	Average	Average	Average			
Choice of variety (susceptible/low susceptibility)	Low susceptibility to phoma	Low susceptibility to foliar diseases				
TFI (if available) or number of passages for chemical protection	4.8 (not-including glyphosate)	5.5	4.2			
Operational costs for pesticides (€/£)	?	?	?			
Mechanical weeding (yes/no)	No	No	No			
Total dose of nitrogen input (units of nitrogen)	170	180	140			
Yield (q/ha)	35	80	72			

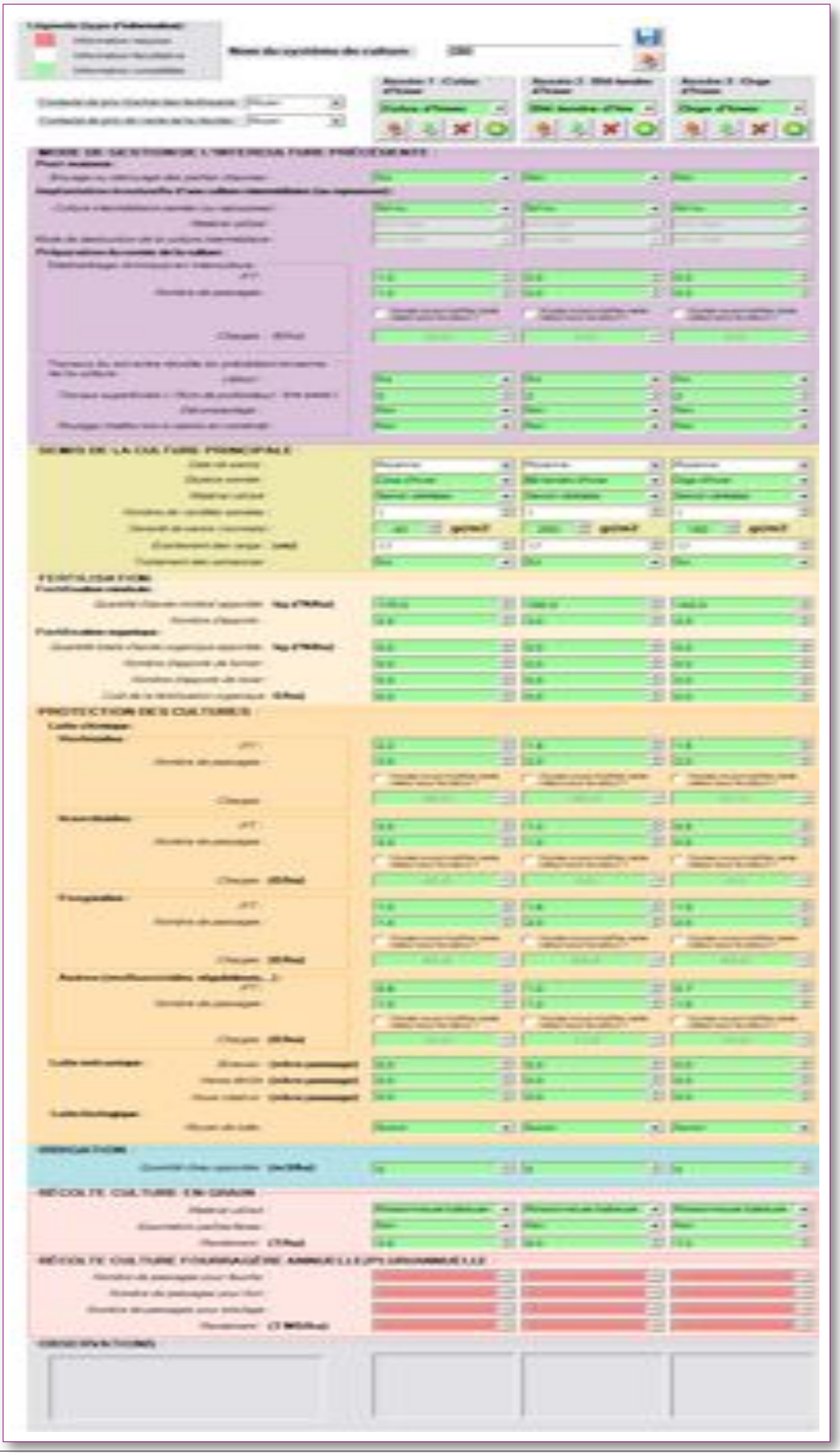
Figure 11: Example of using the description sheet for a CS[g]

Overall, the practices are identical for all fields occupied by the same crop.
Further, no method of protection other than chemical control is used.
The protection strategy used is, therefore, a conventional type.

Comprehensive programme

The description of the cropping system can be entered directly in the STEPHY[a] calculator. This description makes it possible to calculate the indicators for evaluating the initial cropping system (cf. following paragraph).
The description of the CMP[a] required for the calculator reflects our concern to reduce the amount of data which needs to be input by users. Consequently, only those cultural operations having an influence on the evaluation are required. Therefore, for tillage, we have chosen to distinguish only between two types of operation (more than 15 cm deep and less than 15 cm deep) for calculating energy consumption. Furthermore, only one value of energy consumption is used for each type of work, no matter which tool is employed. This simplified description makes it possible to calculate in chart form the indicators used.
The farmer's objectives and constraints, which help sheet H2 can identify, should be noted in the section 'observations'.
N.B.: The information necessary for calculating indicators can be noted on the farm during discussions with the farmer and entered later into the STEPHY[a] calculator to speed the process or if computer access is not available on the farm.

STEPHY[a] calculator - data capture



The rubric « Irrigation » and « harvest » are also in the calculator.

III. 3. Evaluation of the initial cropping system

Objectives :

- Evaluate the CS[a] based on a list of pre-established indicators
- Making it possible to later compare the performance of these to proposed alternative systems

Help available :

Rapid programme

- Support sheet S2B: Simplified description of CS[a]

Comprehensive programme

- STEPHY[a] calculator (cf. S3 for model)
- French Ministry of Agriculture's TFI calculator
- Annex 1: Indicators used for the evaluation of CS[a]

Rapid programme

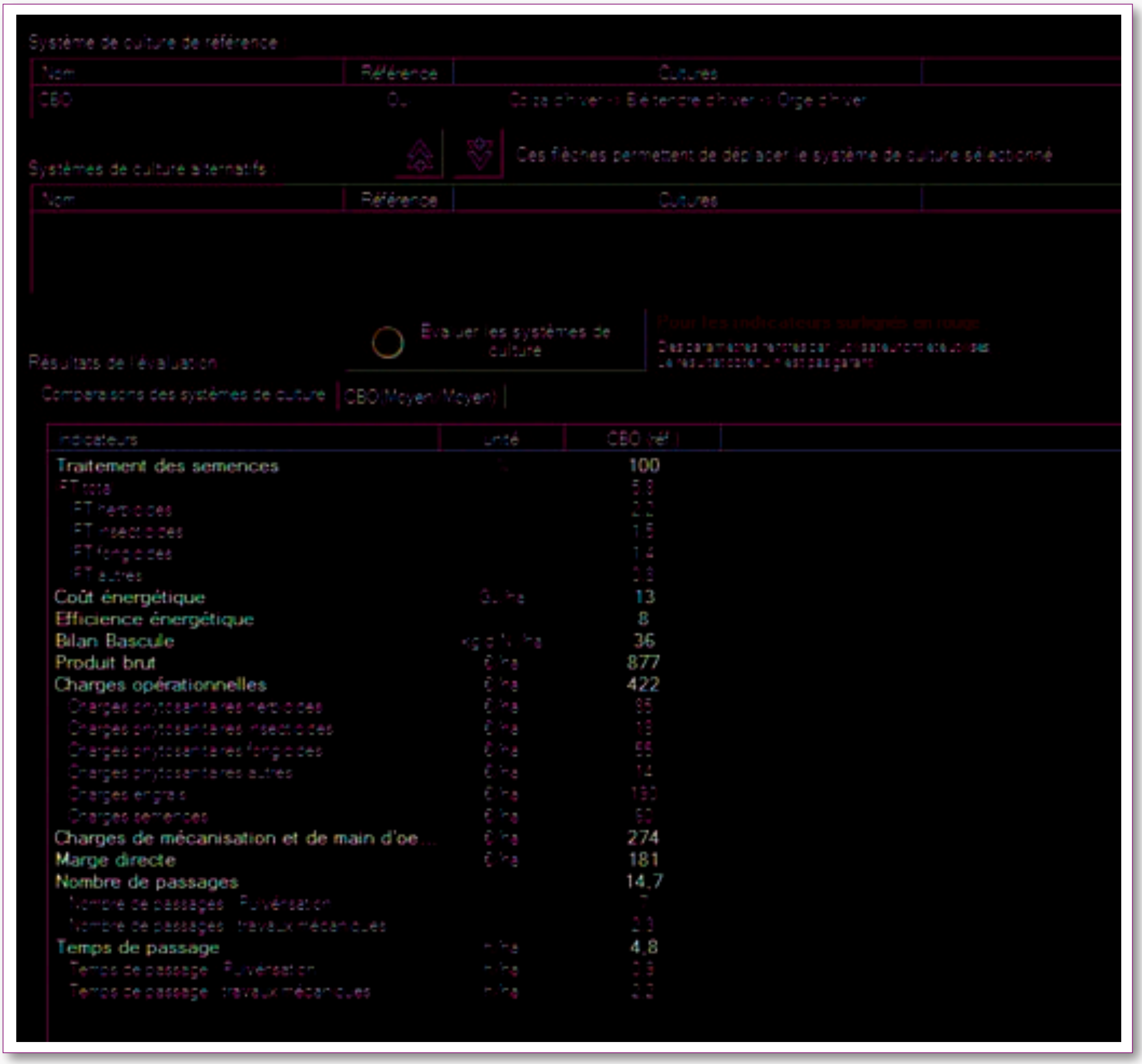
For this option, the current state of the cropping system does not have to be evaluated precisely. In fact, given that we will be evaluating the performances of constructed CS[a] compared to current CS[a], the rapid description of these systems (using support sheet S2B) is sufficient for comparison purposes. However, it should be borne in mind that this evaluation remains simplistic and does not provide an objective view of the performances given to constructed cropping systems.

Comprehensive programme

N.B.: The STEPHY[a] calculator does not calculate TFI. An online tool on the French Ministry of Agriculture website can be used for this.

This evaluation makes it possible to produce a **rapid assessment of the initial CS[a]** and to **demonstrate the performance** of the criteria taken into account. It was decided to not only evaluate the criterion 'pesticides' in order to detect potential negative effects of other types of proposed practices for reducing the use of plant protection products.
A description of the indicators used and the way they are calculated is available in Annex 1.
These indicators are calculated at the cropping system scale and with the objective of comparing the values obtained for the initial system with those of the constructed alternative systems. It makes it possible to judge the effects of modifications to the system not only in the field 'phytosanitaire' (TFI indicator*), but also for other environmental and socio-economic criteria (energy consumption, bilan Bascule (measure of nitrogen balance), direct margin, number of passages in the field etc.).
The description sheets for the CMP[a] and the result sheets can be printed and left with the farmer.

STEPHY calculator - evaluation outputs



IV. STEP 2 : CO-DESIGN OF ALTERNATIVE CROPPING SYSTEMS

This co-design stage between farmers and advisers **explores changes which could be made to the initial system to improve its performance relative to crop protection and with regard to the farmer's desired objectives and constraints**. Here, we are working at the field and rotation scales.

It is a 'virtual' exploration on paper only with no commitments demanded from the farmer and **no a priori constraints to changes apart from agronomic aspects.** Socio-economic aspects are evaluated later. The goal at this stage is to open new horizons to farmers, removing self-imposed barriers to changes in practices such as preconceived ideas regarding lower yields, lower revenues, and higher labour requirements. At this stage, the exploration should free itself entirely of any discussion regarding the concrete steps toward implementing proposed changes in the cropping pattern.

This work will lead to the design of 'alternative' cropping systems which are evaluated at a later stage.

N.B.:

- *Depending on the farmer's objectives and the characteristics of the crop sequence, we may be able to skip this step and work directly on the CMP[a]. For example, for a farmer in France wanting to reduce his TFI to benefit from the agri-environment measures 'phytos hors herbicides' (pesticides except for herbicides), a small adjustment to the CMP[a] can sometimes be sufficient.*
- *Here we are considering only one CS[a] at a time. The changes envisaged, however, can have an effect on all the cropping systems on the farm: to be able to reduce the use of plant protection products in a CS[a], the rotation may be changed. Therefore, in mixed farming systems with livestock, we have to ensure fodder production remains adequate after modifications are made and to readjust if necessary by modifying other systems on the farm. Further, for crops which are subject to quotas, such as beet, we must ensure that proposed modifications do not have any consequences on the ability to satisfy these quotas.*

IV. 1. Considering the rotation

Objectives :

- Identify with the farmer those agronomic levers already used in the current CS[a] at the rotation scale
- Identify supplementary levers which could be interesting to use, according to the objectives

Help available :

Rapid programme

- Support sheet S3: Introduction of alternative technical solutions available for crop protection at the rotation scale
- Help sheet H3: Principal characteristics of arable crops
- Help sheet H4: Help with choosing cover crops

Comprehensive programme

- Support sheet S4: Introduction of alternative technical solutions available for integrated production at the rotation scale
- Help sheet H3: Principal characteristics of arable crops
- Help sheet H4: Help with choosing cover crops

This step serves to evaluate the **farmer's rotation according to the farmer's objectives** established in the previous step. The goal is **to identify supplementary levers that can be introduced to achieve these objectives**. For this, the list of levers available in integrated production is provided in Table 7.

Table 7: Technical solutions used in integrated production at the rotation scale

Diversifying families and species in the rotation to break disease cycles, taking into account time limits for their return and possible precedents
Diversifying families and species in the rotation to produce a parasitic break of pests, taking into account time limits for their return and possible precedents
Diversifying families and species in the rotation to 'despecialise' weed flora
Introduce, one year in three, a long fallow period to allow tillage
Introduce at least one leguminous crop into the rotation
Plant at least one year in three a straw-producing grain crop
Follow the leguminous crop with a winter crop demanding high nitrogen, or as a default, a cover crop[g]
Alternate crops demanding high phosphate with crops needing little phosphate

Levers which can control pests

Rapid programme

The first task is to check if the levers available in integrated production have been used by the farmer. For this, help sheets are available: help sheet H3, which describes the main characteristics of major arable crops, and help sheet H4, which summarises the information which may be required for choosing cover crops.
To record the observations of users during this stage, support sheet S3 lists the technical solutions available at the rotation scale for an alternative crop protection strategy and allows users to rapidly pinpoint the levers to be used.
The second task is to propose feasible changes to the rotation based on the above appraisal, the pest pressure reported by the farmer and the available options identified in the previous step with support sheets S1 and S2. This leads to one or more alternative crop rotations. If needed, support sheet S3 can be used to describe these new rotations, highlighting the changes made and their explanations using a different colour or by circling them.

Example :

N.B.: The approach is identical for both the rapid and comprehensive programmes, so the description above is valid for both.

1. Checking the levers already used (support sheet S3)

Lever available	Implementation in current CS		Implementation in alternative CS1		Implementation in alternative CS2	
	Rotation : OR - WW - WB		Rotation : OR - WW - flax - WW - pea - WW		Rotation :	
	Probably yes	Probably no	Probably yes	Probably no	Probably yes	Probably no
Diversify families and species in the rotation to break the disease cycle, taking into account the time period before the return of crops and the possible precedents	x					
Diversify families and species in the rotation to break the pest cycle in relation to animal pests, taking into account the time period before the return of crops and the possible precedents	x					
Diversify families and species in the crop sequence to 'despecialise' weed flora		x				
Introduce a long fallow period one year in three to allow tillage		x				

Figure 11 : Example of using the description sheet for a CS[a]

2. Proposed modifications in the rotation

The farmer's objectives in this system are, in the first instance, to control weeds (rye-grass and foxtail) in cereals and pests in oilseed rape. However, we realise that the levers which allow us to 'despecialise' weeds are not used.
By thinking about the rotation, we can therefore improve the management of weeds.

In the oilseed rape/wheat/winter barley system, three winter crops follow each other. This leads to a specialisation of weeds which makes the situation harder to control. This may explain the problems experienced in cereals. The principal solution is based on diversifying the sowing periods. For example, we can replace winter barley with spring barley. This allows for a long fallow period for tillage (creation of stale seed beds). Doing this, we arrive at a rotation of oilseed rape/wheat/spring barley.

However, to diversify the families present in the rotation and therefore reduce the risk of diseases, we could introduce peas into the rotation, a crop that is already grown elsewhere on the farm. This pulse crop introduces nitrogen into the system and, again, provides a long fallow period making tillage possible, particularly for the control of weeds. Even though the markets for this crop are not necessarily obvious, the crop has many advantages. Another alternative would be to introduce field (broad) beans, which offer the same advantages. We could arrive, therefore, at a rotation of oilseed rape/wheat/spring protein (peas or beans)/winter barley.

With regard to diseases, we note that oilseed rape returns every three years. This frequency is a little high and can lead to the development of persistent diseases in this crop (sclerotinia). We could therefore suggest lengthening the rotationg to address this. As a market exists for flax, we could suggest it be introduced, taking into account this would also make it possible to diversify the sowing periods for spring crops (cf. help sheet H3). However, we could also suggest that wheat returns several times in the rotation to guarantee the farm's revenue. We arrive therefore at a rotation of oilseed rape/wheat/flax/wheat/spring protein (peas or beans)/wheat.

To take it further still, we could suggest sowing of cover crops. Help sheet H4 provides information to help choose these crops. Niger, for example, can cover the soil during autumn and therefore smother autumn weeds, limiting their seed set. This cover crop has other advantages too, trapping nitrogen in the soil and can be easily killed off by frost or mechanical means.
After discussions, we arrive therefore at three alternative rotations which incorporate in different ways the farmer's objectives. Each should then be discussed and evaluated.
However, for the next steps of the programme, we will take only the example of the oilseed rape/wheat/flax/wheat/spring protein crop (peas or beans)/wheat system, which is the most complex and most interesting to describe here. The levers it introduces are listed in Figure 13.

Lever available	Implementation in current CS		Implementation in alternative CS1		Implementation in alternative CS2	
	Rotation : OR - WW - WB		Rotation : OR - WW - flax - WW - pea - WW		Rotation :	
	Probably yes	Probably no	Probably yes	Probably no	Probably yes	Probably no
Diversify families and species in the rotation to break the disease cycle, taking into account the time period before the return of crops and the possible precedents	X		X			
Diversify families and species in the rotation to break the pest cycle in relation to animal pests, taking into account the time period before the return of crops and the possible precedents	X		X			
Diversify families and species in the crop sequence to 'despecialise' weed flora		X	X			
Introduce a long fallow period one year in three to allow tillage		X	X			

Figure 12 : Identifying the levers used in the current rotation and suggested introduction of new levers
In red, modifications to the system.

Comprehensive programme

In the comprehensive programme, indicators have been created to evaluate not only the introduction of the levers available for crop protection, but also for other elements of the system (such as fertilisation) to encourage further thought. A table for rapid evaluation of the introduction of available levers, based on simple indicators, is provided in support sheet S4. Help sheets H3 and H4 provide useful information for this table, listing the principal characteristics of arable and intermediate crops.
Always bearing in mind the farmer's objectives, constraints and means, suggestions for modifying the cropping system can be made to improve pest management.
The possible system or systems constructed can then be described in a new calculation sheet.

Example :

1. Identification of the levers already used (support sheet S4)

Targets in the pest cycle	Technical solutions available	Indicators	Implementation by the farmer					
			Implementation in current CS		Implementation in alternative CS 1		Implementation in alternative CS 2	
			Rotation : OR - WW - WB		Rotation : OR - WW - flax WW - pea - WW		Rotation :	
			Probably yes	Probably no	Probably yes	Probably no	Probably yes	Probably no
Limit the presence of pests in general in the crops	Diversify families and species in the rotation to break the pest cycle, taking into account the time period before the return of crops and the possible precedents	Absence of precedents to be avoided	x					
Limit the presence of diseases in the crops	Diversify families and species in the rotation to break the pest cycle, taking into account the time period before the return of crops and the possible precedents	At least two different families	x					
		At least three different species cultivated	x					
		Respect for time period between same crop		x				
Limit the specialisation of weed flora and reduce the seed bank	Diversify families and species in the rotation for 'despecialising' weed flora	At least three sowing periods in four		x				
		Ratio of autumn crops to spring crops close to 2/3		x				
Reduce the population of animal pests in the field	Introduce a long fallow period one year in three to allow tillage	At least one long fallow period every three years		x				
Add nitrogen to the system	Introduce at least one leguminous crop into the rotation	At least ¼ of leguminous crop in the rotation		x				
Maintain level of OM in the soil	Sowing a grain crop returning straw at least one year in three	At least one grain crop returning straw every three years	x					
Trap nitrogen in the soil in winter period	Follow a leguminous crop by a winter crop with high N demand or, as a default, a cover crop	A leguminous crop followed by a winter crop with high N demand	-					
Maintain chemical fertility of soil	Alternate crops with high PK demand with less demanding crops	Less than 30% of crops with high P demand	x					
		Less than 30% of crops with high K demand	x					

2. Suggestions for modifying the rotation

N.B.: The process is identical for the two programmes and has already been described for the rapid programme. Therefore, it is not repeated here. We arrive at a rotation of oilseed rape/wheat/flax/wheat/spring protein crop (peas or beans)/wheat.

			Implementation by the farmer					
Targets in the pest cycle	Technical solutions available	Indicators	Implementation in current CS		Implementation in alternative CS 1		Implementation in alternative CS 2	
			Rotation : OR - WW - WB		Rotation : OR - WW - flax WW - pea - WW		Rotation :	
			Probably yes	Probably no	Probably yes	Probably no	Probably yes	Probably no
Limit the presence of pests in general in the crops	Diversify families and species in the rotation to break the pest cycle, taking into account the time period before the return of crops and the possible precedents	Absence of precedents to be avoided	x		x			
Limit the presence of diseases in the crops	Diversify families and species in the rotation to break the pest cycle, taking into account the time period before the return of crops and the possible precedents	At least two different families	x		x			
		At least three different species cultivated	x		x			
		Respect for time period between same crop		x	x			
Limit the specialisation of weed flora and reduce the seed bank	Diversify families and species in the rotation for 'despecialising' weed flora	At least three sowing periods in four		x	x			
		Ratio of autumn crops to spring crops close to 2/3		x	x			
Reduce the population of animal pests in the field	Introduce a long fallow period one year in three to allow tillage	At least one long fallow period every three years		x	x			
Add nitrogen to the system	Introduce at least one leguminous crop into the rotation	At least ¼ of leguminous crop in the rotation		x		x		
Maintain level of OM in the soil	Sowing a grain crop returning straw at least one year in three	At least one grain crop returning straw every three years	x		x			
Trap nitrogen in the soil in winter period	Follow a leguminous crop by a winter crop with high N demand or, as a default, a cover crop	A leguminous crop followed by a winter crop with high N demand	-		x			
Maintain chemical fertility of soil	Alternate crops with high PK demand with less demanding crops	Less than 30 % of crops with high P demand	x		x			
		Less than 30 % of crops with high K demand	x		x			

Figure 13 : Evaluating the introduction of the levers available in integrated production on the current rotation and suggested modifications

In red, modifications to the system.

IV. 2. Considering the crop management plans

Objectives :

- Identify with the farmer the agronomic levers already introduced in his current CS[a] at the CMP[a] scale
- Identify supplementary levers for introduction according to objectives

Help available :

Rapid programme

- Support sheet S4: Implementation of alternative technical solutions available for crop protection at the CMP[a] scale
- Help sheet H5: Classification of practices contributing to pest control at the field level according to efficacy
- Help sheet H6: Known combinations of alternative methods for control of pests
- Help sheet H7: Examples of antagonisms of practices on different pests

From earlier steps :

- Support sheet S1: Summary diagram for the diagnosis of the farm
- Support sheet S2: Description of CS[a]

Comprehensive programme

- Support sheet S5: Mechanism and implementation of alternative technical solutions for crop protection at the CMP[a] scale
- Help sheet H5: Classification of practices contributing to pest control at the field level according to efficacy
- Help sheet H6: Known combinations of alternative methods for control of pests
- Help sheet H7: Examples of antagonisms of practices on different pests
- Help sheet H8: Typology of pests

From earlier steps :

- Support sheet S1: Summary diagram for the diagnosis of the farm
- Description sheet of current system (STEPHY[a] calculator)

At this stage it is necessary to **analyse the consistency between the risk level linked to pests (evaluated on the basis of major problems reported by the farmer and the control methods already used) and the level of plant protection product use.** It may be possible to reduce the number of passages in the field without any major modifications if the farmer ‘over protects’ his crops.

Stage 1 : The first step is to **identify the pest control levers already introduced by the farmer**, based on the description of the CMP[a]. This work should first be done for the pest or pests, identified in step 1, as posing the greatest problem in the CS[a] (support sheets S1 and S2 or the description sheet in the STEPHY[a] calculator).

Stage 2 : According to the conclusions drawn in this discussion, **suggestions for new pest control strategies can be made**. The support sheets identifying the farmer’s constraints and means available (support sheets S1 and S2 or the description sheet in the STEPHY[a] calculator) make it possible at this stage to identify practices which can be employed.

Stage 3 : Subsequently, we need to **verify that the practices introduced for pest control do not have major negative impacts on other pests in the system**. To help this process, a list of the major antagonistic effects is available in help sheet H7.

According to the efficacy of the practices chosen to protect the system from its principal pests, supplementary practices can be used to ensure effective protection against other pests.

At the end of this step, we can complete the description of the rotation or sequences obtained with the new CMP[a] for each crop in the rotation. For crops which are not familiar to the farmer, it may be possible to use CMP[a] of the ‘regional’ type, available from Chambers of Agriculture, technical institutes or cooperatives. The CMP[a] in Annex 2 can also be used to support this process and be adapted for local use.

Rapid programme

Table 8 lists the levers available for pest control at the CMP[a] scale. Using this table we can rapidly highlight those levers already used by the farmer (stage 1) and then suggest new practices which could be used according to the problems facing the farmer and the means available to him (cf. support sheets S1 and S2). However, it is not possible to explain to farmers how these levers work on the pest concerned.
Help sheets H5 and H6, which classify the levers according to their efficacy and suggest proven combinations of practices respectively, can help in prioritising those levers which should be introduced.

Table 8 : Levers available to control pests at the CMP[a] scale

a. For diseases

Technical solutions available
▸ Limiting contamination through farm machinery ▸ Tillage to bury crop residues ▸ Shredding of crop residues ▸ Destruction of volunteers and host weeds ▸ Choosing uncontaminated seeds ▸ Choosing resistant varieties ▸ Choosing tolerant varieties ▸ Reduction of sowing density ▸ Changing sowing dates ▸ Combination of species/varieties ▸ Adjusting nitrogen inputs according to the crop's production needs to limit the over-development of leaf surfaces ▸ Biological control

b. For weeds

Technical solutions available
▸ Limiting contamination through farm machinery ▸ Tillage (ploughing) to bury seeds ▸ Stale seedbeds: for exhausting seed bank ▸ Mowing of field borders ▸ Choosing competitive varieties (according to phenological characteristics) ▸ Changing sowing dates ▸ Increasing sowing density, reducing space between rows ▸ Combination of species and varieties ▸ Adjusting nitrogen inputs according to the crop's production needs to encourage development ▸ Mechanical weeding

c. For animal pests

Technical solutions available
▸ Shredding of crop residues ▸ Tillage ▸ Destruction of volunteers and host weeds ▸ Changing sowing dates ▸ Reduction of sowing density ▸ Combination of species and varieties ▸ Choosing resistant varieties ▸ Choosing tolerant varieties ▸ Biological control ▸ Adjusting nitrogen inputs according to the crop's production needs to limit the over-development of leaf surfaces ▸ Ensure a good level of nitrogen nutrition for more vigorous plants ▸ *Creation of attractive/repellent zones* ▸ *Creation of trap crops*

The protection methods in italics work at scales other than the field scale.

To finish the process, the new rotation (or crop sequences) along with the technical elements of the CMP[a] for each crop involved in the crop protection strategy are briefly described using support sheet S2.

Example :
How sheet S4 is completed, based on cropping wheat, is shown in Figure 14.
The reasoning behind the changes made to the system is identical for both the rapid and comprehensive programmes. It is explained below and not duplicated for the comprehensive programme.

Reflecting on the CMP[a] for wheat: we start with weeds because grass weeds in cereals pose the biggest problem for the farmer. We note in the table of support sheet S4 the levers which are used in the initial system: here, the farmer uses only chemical control. To improve the management of weeds, we could introduce spring crops to break the weed cycle: this is what has been done during our discussion on the rotation. Tillage can also be used for managing weeds and here the farmer had decided to stubble plough twice and create one stale seed bed before the wheat.
To ensure the stale seed bed is as effective as possible in limiting the appearance of grass weeds, it has been decided to sow wheat later than usual.
The principal levers for the management of weeds are therefore being employed (cf. help sheet H7).
The equipment is available for conducting mechanical weeding, so it has been decided to use this lever and pass through the crop with a harrow to destroy weeds if necessary.
According to annex 2, the introduction of this set of practices will make it possible to reduce by one the number of herbicide applications and reduce the TFI[a] for herbicides by 0.5.
Finally, we summarise on sheet S4 those practices which are envisaged for the alternative CS[a].
Second, we verify the efficacy of these practices on diseases. The pressure from septoria is considered a secondary pressure compared to that generated by weeds, but is nevertheless present. To manage this disease, whose spores are extremely mobile, it has been decided to adopt a low sowing density (between 160 and 180g/m^2) and use a resistant variety or a combination of resistant varieties and to cancel the application of nitrogen during the tillering stage to reduce the vegetative biomass produced. We can then reduce fungicide applications by one, reducing the TFI[a] by 0.6.
Animal pests are not a source of major pest pressure in wheat so here we need only check that the practices introduced do not conflict with their management. This is OK here and, furthermore, late sowing means we can avoid autumn aphids. Insecticide treatments in wheat are therefore rare and here the TFI[a] for insecticides is 0.

				Crop : winter wheat			
				Implementation in current CS		Implementation in alternative CS 1	
Lever available	Effects on			Reminder of Rotation : OR - WW - WB		Reminder of Rotation : OR - WW - flax WW - pea - WW	
	Weeds	Diseases	Animal pests	Probably yes	Probably no	Probably yes	Probably no
Shredding of crop residues		x	x	x		x	
Destruction of volunteers and host weeds	x	x	x		x	x	
Use of uncontaminated seed		x		x		x	
Choice of resistant/tolerant varieties		x	x	x (diseases)	x (animal pests)	x	x
Choice of competitive varieties (according to their phenological characteristics)	x			x			x
Limiting contamination through equipment	x	x		x		x	
Tillage (alternating superficial cultivation and ploughing) in association with the rotation (burying seeds and sources of inoculum)	x	x	x		x	x	
Stale seed beds: to exhaust seed bank	x		x		x	x	
Shredding of borders	x			x		x	
Shifting sowing date	x	x	x		x	x	
Increasing sowing density, reducing spacing of rows	x	x	x		x		x
Reducing sowing density	x	x	x		x	x	
Combination of species and varieties	x	x	x		x	x	
Adjusting nitrogen inputs to the production needs of the crop to encourage its development	x	x	x	x		x	
Mechanical weeding	x		x		x	x	
Biological control		x	x		x		x
Landscape management		x	x		x		x

Figure 14 : Example of a completed sheet for the introduction of agronomic levers at the CMP scale for wheat
In red, those levers which can have an antagonistic effect between pests.

The system we arrive at is then described with the help of support sheet S2 (cf. Figure 15).

	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
CROP	Oilseed rape	Winter wheat	Flax	Winter wheat	Spring pea	Witner wheat
Ploughing (yes/no)	Yes	Yes	Yes	Yes	No	Yes
Tillage during fallow period (number of passages)	2	3 (including 2 stale seed beds)	0	3 (including 2 stale seed beds)	2	3 (including 2 stale seed beds)
Sowing date (early/average/late) and density (low/average/high)	Early date average density	Late date Low density	Low density	Late date Low density	Low density	Late date Low density
Choice of variety (susceptible/low/susceptibility)	Varieties resistant to phoma	Combinaison of resistant varieties		Combinaison of resistant varieties		Combinaison of resistant varieties
TFI (if available) or number of passages for chemical protection	4.5 (herbicides TFI reduced because of mechanical weeding and insecticide TFI reduced because of early sowing date and no growth regulator	2.9 (no insecticide for aphids in autumn, fungicides and herbicides reduced)	4	2.9 (no insecticide for aphids in autumn, fungicides and herbicides reduced)	4	2.9 (no insecticide for aphids in autumn, fungicides and herbicides reduced)
Operational costs for pesticides (€/£)	?	?	?	?	?	?
Mechanical weeding (yes/no)	yes	no	yes	no	no	no
Total dose of nitrogen input (units of nitrogen)	170	160	100	170	0	140
Yield (q/ha)	30	75	20	75	48	75

Figure 15 : Description of the proposed alternative CS[a]

Comprehensive programme

Stage 1 : Using support sheet S5 we can position the effects of different practices in the development cycle of the three pest categories and on crop status. It is offered in the form of a diagram and a table so users can choose the format they find easiest. This sheet can be used to identify the practices introduced by the farmer (circling them in the diagram for example) and their mode of action. It allows discussions to be held about their efficacy, Users can consult help sheet H5 to encourage these discussions as it classifies different pest control practices according to efficacy.

Stage 2 : For considering new strategies, support sheet S5 and help sheet H5 are again used.
To further help users, a list of proven combinations of actions for different categories of pests is available in help sheet H6. Annex 2 also provides examples of crop management plans according to different levels of intervention.
We therefore produce a combination of practices for controlling the principal pest or pests. These practices for introduction in the alternative cropping systems should be recorded in the diagrams in support sheet S5.

For this step, help sheet H8 suggests those actions which should be given priority according to the characteristics of the pests confronting the farmer (a characterisation of pests is currently being compiled and will be available online). Users can choose certain types of action in accordance with the characteristics of the pests present in the CS[a] (for example, burying residues can provide better disease control for saprotrophic[g] pathogens). It allows the protection strategy to be more finely tuned according to the principal pests in the CS[a], though we must always pay attention to possible antagonistic effects between practices and to knock-on effects.
The description of the resulting alternative cropping systems can be made directly in the calculator ready for the next step, the evaluation of these CS[a].

Example :

The rationale for the crop management plan for wheat was explored earlier in the rapid programme, so is not repeated here. Figures 16 and 17 show how the diagrams illustrating interactions between practices, pest cycles and crop status can be used.

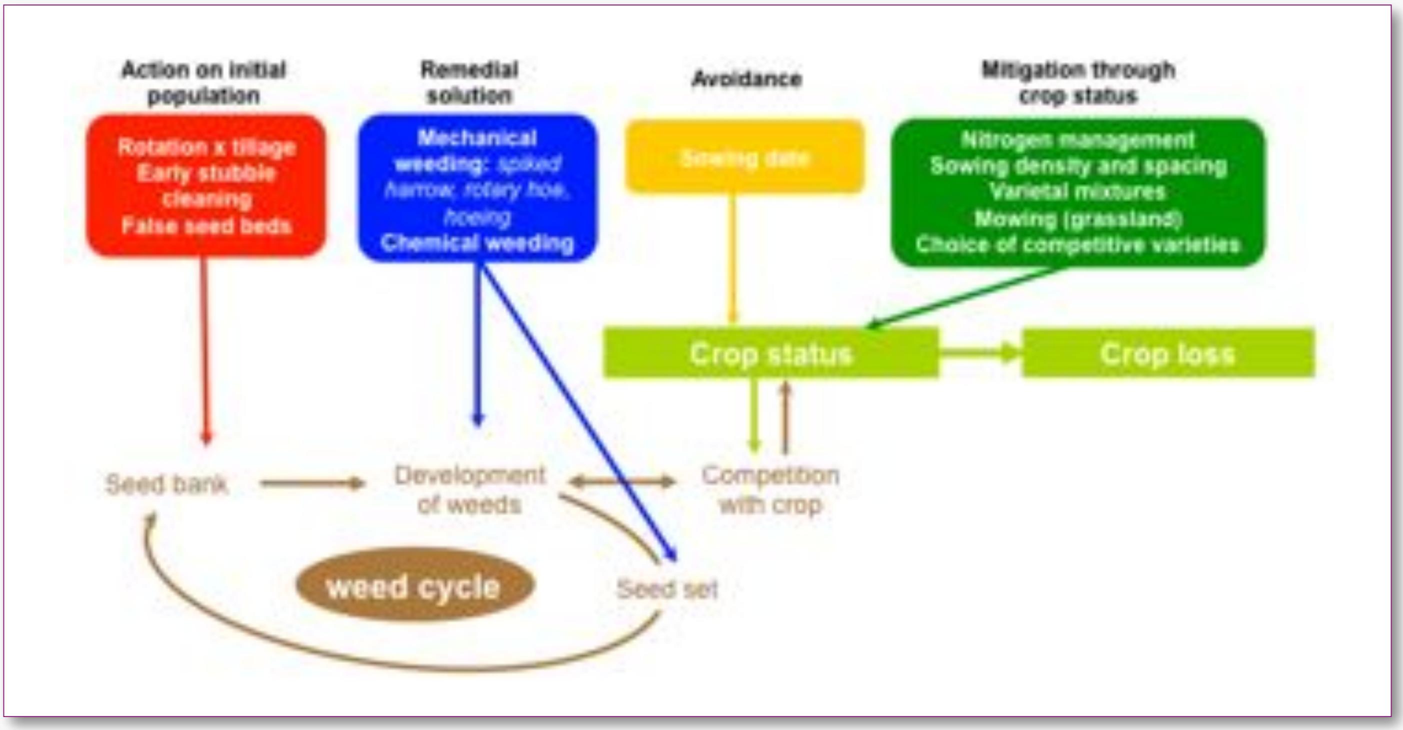


Figure 16 : Example of the use of the diagrams showing interactions between practices/pests/crop status (1)

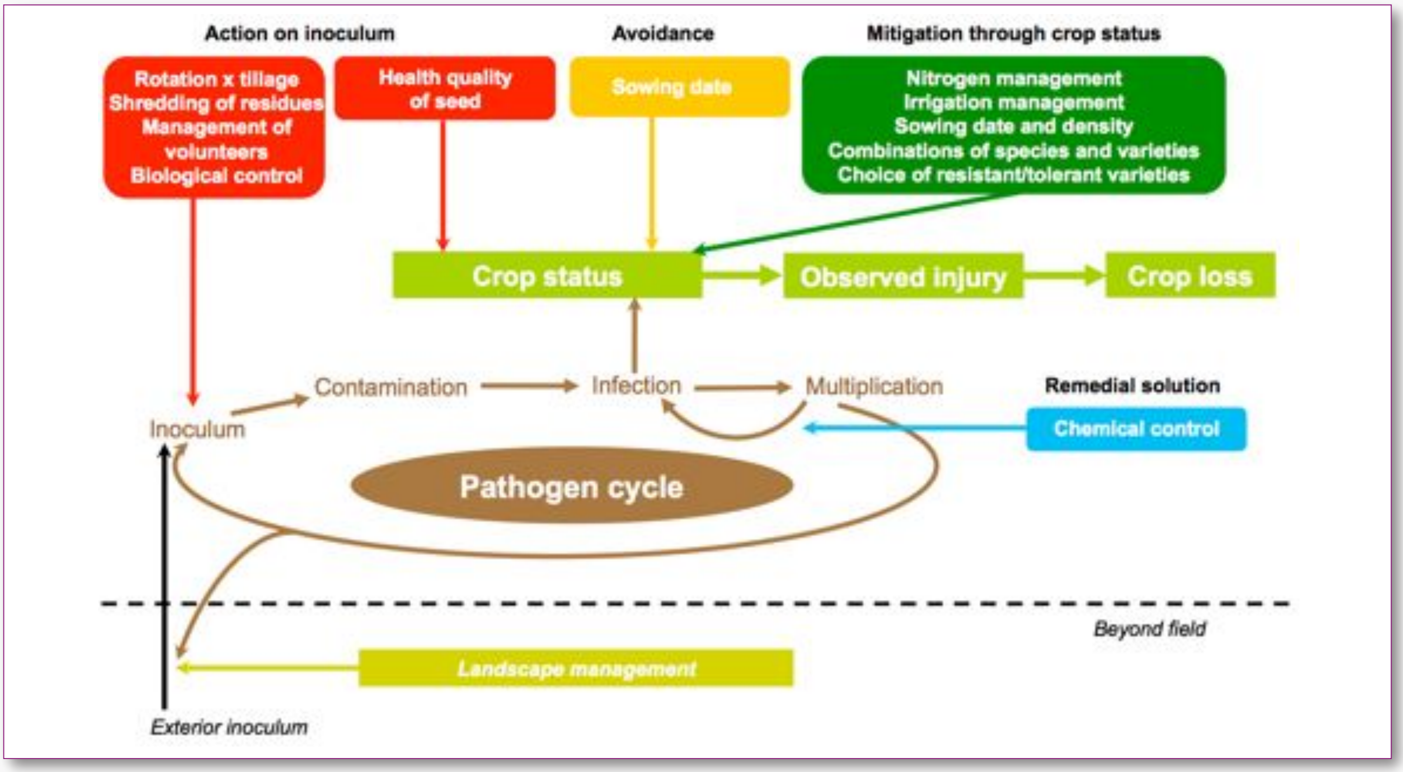


Figure 17 : Example of the use of the diagrams showing interactions between practices/pests/crop status (2)

V. STEP 3 : EVALUATING CROPPING SYSTEMS COMPARED WITH THE INITIAL CROPPING SYSTEM

Objectives :

- Evaluate the performances of alternative CS[a] compared with the initial CS[a]

Help available :

Rapid programme

- Support sheet S5: Simplified evaluation of the performances of alternative CS[a]

From previous steps :

- Support sheet S1: Summary diagram for the diagnosis of the farm
- Support sheet S2: Description of CS[a]

Comprehensive programme

- STEPHY[a] calculator (cf. S6 for model)
- French Ministry of Agriculture TFI calculator
- Annex 1: Indicators used for the evaluation of CS[a]

In this step, the task is **to verify that the changes suggested do indeed help reduce the use of plant protection products without adversely affecting other aspects of the system.**

Rapid programme

A rapid evaluation of the impact of new practices on various aspects (TFI[a], number of passages in the field, conflicts with other work, yields, costs) allows us to see changes in these criteria between current and newly constructed CS[a]. Support sheet S5 can be used to summarise this evaluation, drawing on the characterisation of the current CS[a] made in step 1 (support sheet S2).
This approach remains **very qualitative** because it uses a comparison with the initial system and references are not always available for newly introduced crops. It does not necessarily make it possible to appreciate the changes in performances on the whole cropping system. Further, it is not possible to appreciate in a concrete form potential changes in the system: a farmer could think, for example, that introducing mechanical weeding will cause a big increase in energy consumption and an adviser cannot show this is not the case using this simplified evaluation. The calculator offers this possibility.

Example

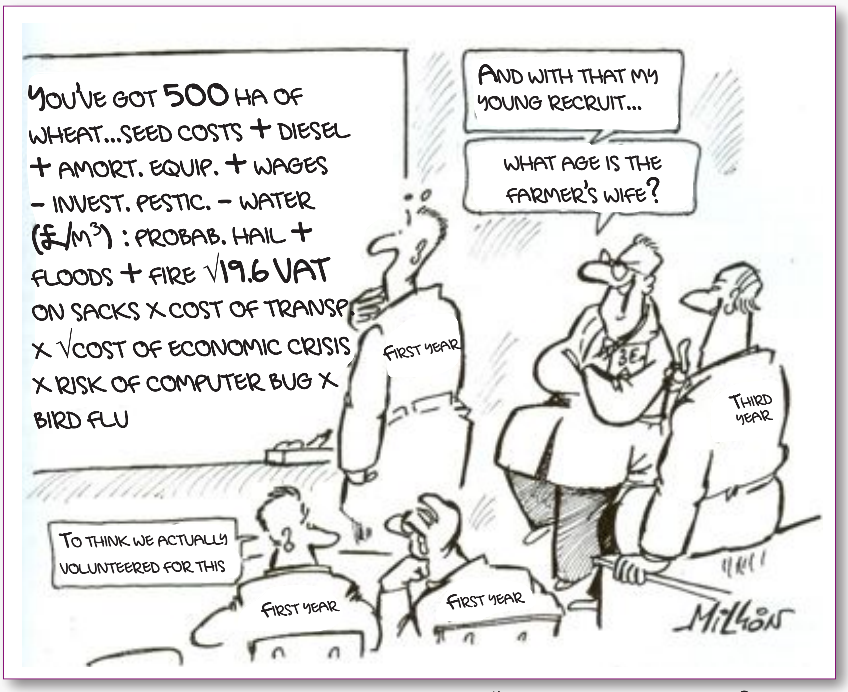
The indicators below have been chosen in order to conduct a very rapid evaluation, comparing CS on various criteria: environment through TFI, economy through yield, costs and direct margin, energy through the quantity of nitrogen inputs and the social aspect through the number of passages in the field.
These tables should be completed based on the description of CS made in support sheet S2A. The task is to translate the changing trends in the indicators, comparing crop by crop and then overall, the current and alternative CS.
If new crops are introduced, compare only those found in the two CS, then judge the overall change in the indicators by estimating the value of the indicators for new crops.
For TFI, see if there is an overall reduction in the number of passages through the introduction of alternative practices compared to the current CS.
For costs, estimate the variations due to changes in pesticide and fertiliser consumption. The margin can then be calculated in relation to the changes forecast in costs and yield.
The number of passages in the fallow period records the tillage conducted (stubble cleaning, stale seed beds etc.).

Indicator	Alternative CS 1 : OR - WW - flax - WW - pea - WW						
	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Average for the CS
TFI	↘	↘		↘		↘	↘
Yield (t/ha)	↘	↘		↘		↘	↘
Costs (€/£)	↘	↘		↘		↘	↘
Direct margin (€/£)	→	→		→		→	→
Nitrogen input	→	↘		↘		↘	↘
Number of passages in fallow period	↘			↗		↗	→
Number of passages for mechanical weeding	↗	↗		↗		↗	↗

Through this quick evaluation, we can see that the proposed alternative cropping system is less reliant on pesticides, which makes it possible to reduce the farmer's costs. Therefore, even if yields are reduced, the system can produce a margin equivalent to that of the current system when the sale price of products and the cost of inputs are equivalent. On the other hand, the number of mechanised interventions is increased (passages during fallow period and mechanical weeding). Working hours and energy consumption in this system could therefore be higher. With regards to energy consumption, its increase due to the higher number of passages in the field may be offset by the reduction in the quantities of nitrogen used in the system. The qualitative evaluation made in this programme does not allow us to be certain on this point. To go further, it is necessary to conduct a quantitative evaluation, which can be done using the STEPHY[a] calculator (see comprehensive programme).

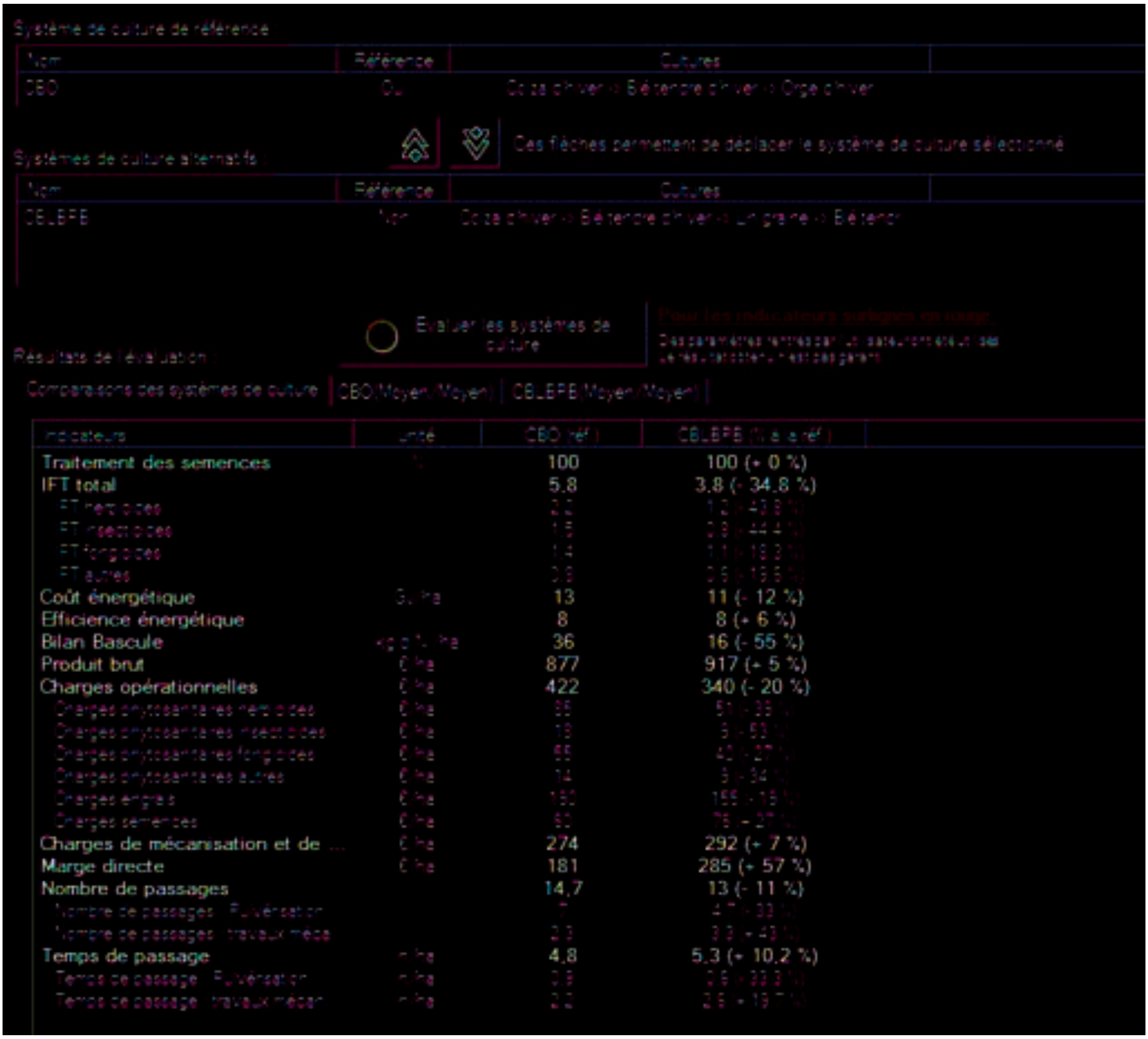
Comprehensive programme

The STEPHY[a] calculator provides a quantitative evaluation of proposed alternative solutions. The crop management plans for each crop within each of the different systems envisaged are entered into the calculator. The indicators characterising the initial state for the alternative systems are calculated automatically.



Cartoon by Robert Rousso in Le Courrier de l'environnement from INRA n° 57, p. 89

STEPHY Calculator - comparative CSª evaluation



Furthermore, using the calculator we can **run simulations** to vary the characteristics of the cropping system (yield, number of mechanical interventions etc.) and see their influence on the values of the indicators. For example, it is interesting to see how a variation in estimated yield of introduced crops or of pre-existing crops managed in a different way can influence the profit margins associated with each system. To do this, we can reduce or increase the yield by 5q/ha and see the effects on the calculated indicators. The calculator also offers different price contexts both for the sale price of products and the purchase price of fertilisers. We can therefore simulate changes in the economic performance of the cropping system in different economic situations and estimate the sensitivity of new systems in different contexts.
However, to compare different systems, it is necessary to use the same price context for each one.

VI. STEP 4 : DISCUSSION OF RESULTS

The comparison of the performances of different cropping systems means we can **discuss with the farmer the introduction of the proposed changes on his farm,** whether it be a test field or a portion of the farm. In this step, the proposed changes are adapted according to the possibilities, the constraints of the cropping pattern and their consequences for the whole farm. This is particularly important in mixed crop-livestock farming, where it is important to ensure that fodder supplies satisfy livestock needs. There is, however, some flexibility in this regard as nutrition needs can also be satisfied by reorganising animal feed rations.
The RMT SDCI[a] sheets describe in more concrete terms the introduction of the practices discussed in this guide (crops concerned, modes of action, pests affected, necessary conditions: climate, type of soil etc.) to ensure their efficacy and effects in practice. They can subsequently be used when introducing the changes discussed here.
We could also envisage meetings with groups of farmers to present the alternative cropping systems, selected by farmers in the group, and their performances, discussing with the group the introduction of the selected practices. Holding a meeting which includes farmers accustomed to these practices means we can discuss their technical particularities and implementation.

During this period of reflection on the implementation of the constructed system, **it is important not to consider the revenue generated by the system per year**. In fact, the introduction of new crops chosen for their agronomic qualities, and notably for crops producing margins lower than wheat such as peas, can mean that in certain years the margin for the rotation may be reduced. Moreover, to balance the farm's revenues, all the cropping systems have to be made coherent in order to meet fodder requirements where needed, to respect the farm's quotas and to ensure the presence each year of a proportion of cash crops compared to crops chosen on the basis of their 'agronomic' value (peas, lucerne).

Discussion with the farmer will **raise any obstacles or blocks on the farm which will hinder the introduction of the proposed cropping systems**. It is interesting to **assess whether these are technical obstacles**, in which case the adviser can help the farmer find a solution, or relates to **concerns about change**. In the latter case, the role of the adviser is to reassure the farmer about the risks he thinks he is taking in changing the system by showing him the performances of these systems through references, preferably local, or through visits to test fields or farms using these practices.

Within the programme described in this guide, only an a priori evaluation of alternative systems is offered. We do not tackle the monitoring of their implementation or the a posteriori evaluation of performances, which are outside the guide's scope.

Farmer F1 describes the performances of his system :
«Through the introduction of these practices (lengthening the succession, alternating spring and autumn crops, choice of tolerant/resistant varieties, stale seed beds, changing sowing dates and mechanical weeding), my TFI[a] has reached the level of 2, and there is still room for improvement, while the local average is 5. From an environmental point of view, we are heading in the right direction, without endangering the economic results.»

PART II: A METHOD FOR CO-DESIGNING CROPPING SYSTEMS LESS RELIANT ON PESTICIDES

Summary :

• The approach described in this section makes it possible to **consider with a farmer alternative cropping systems with the objective of reducing their dependence on the use of pesticides**. It is based on a preliminary characterisation of the context in which these systems are situated to take into account the farm's advantages and constraints during the design stage. We use a global approach, taking into account the whole farm, to draw up propositions for the farmer.

• **The design of cropping systems less reliant on pesticides cannot be achieved by simply replacing chemical control with other control methods**. It is a case of finding a combination of levers which together make it possible to control pests in these systems and to ensure the sustainability of these control methods.

• **There are no 'typical' effective combinations for managing pests**: these combinations are to be constructed case by case, according to the means available and the constraints involved. Nevertheless, the guide provides examples of combinations **to be adapted locally.**

• The references provided in this guide **should be adapted and enriched by local references**. Innovative cropping systems can be tested by farmers, Chambers of Agriculture and agricultural schools etc. These local experiences should be used for considering the implementation of new systems on the farm.

Farmers F1, F2 and F5 sum up their systems :

«It has restored my enthusiasm for farming.»

«It's not easy to manage, but it makes the work interesting.»

«I am calmer when I go to see my crops.»

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LINKS

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https://colloque.inra.fr/systemes_cultures_innovants_et_durables (in French)
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ANNEXES

CONTENTS

LIST OF ABBREVIATIONS

The terms in this list are marked by the [a] sign in the text.

ACTA	Association de Coordination Technique Agricole
AD	Applied dose
ADAR	Agence pour le Développement Rural Agricole
ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie
BYDV	Barley yellow dwarf virus
CA	Chamber of Agriculture
CMP	Crop management plan
COMIFER	Comité Français pour le développement de la Fertilisation Raisonnée (French committee for the development of rationalised fertilisation)
CS	Cropping system
CSP	Commercial speciality
CUMA	Coopérative d'Utilisation du Matériel Agricole (cooperative of users of agricultural machinery users)
CV	Calorific value
DM	Direct margin
DSS	Decision Support System
E	Energy
F	Farm
GG	Greenhouse gas
GP	Gross product
ITB	Institut Technique de la Betterave (French technical institute for beet)
ITCF	Institut Technique des Céréales et des Fourrages (French technical institute for cereals and forage)
K	Potassium
LMC	Labour and machinery costs
MAP	Ministère de l'Agriculture et de la Pêche (French Ministry of Agriculture and Fishing)
N	Nitrogen
OC	Operational costs
OM	Organic matter
P	Phosphorous
RD	Recommended dose
RMT SDCI	Réseau Mixte Technologique Systèmes de Culture Innovants (joint technology network for innovative cropping systems)
SCEES	Service Central des Enquêtes et Etudes Statistiques (French service for surveys and statistics)
TFI	Treatment Frequency Index
UNIP	Union Nationale Interprofessionnelle des plantes riches en Protéines (National Interprofessional Union of plants rich in proteins)
VLS	Very low susceptibility

ANNEX 1 : INDICATORS USED FOR THE ENVIRONMENTAL EVALUATION OF CROPPING SYSTEMS

OBJECTIVES AND CONSTRAINTS OF THE EVALUATION

- We are seeking to make an overall evaluation of the CS and not CMP by CMP.
- For modified CS, the evaluation is made a priori => we have to conduct the evaluation without precisely knowing the value of certain variables (yields, plant protection products used etc.). Where required, we therefore use hypotheses for these variables.
- The evaluation should be made rapidly (the complete process should take only half a day, or one day maximum).

➔ A set of 10 indicators, sometimes qualitative, has been built, allowing practices to be evaluated in relation to plant protection products and those areas susceptible to the effects of changes in practices (energy, nitrogen, workloads, gross margins etc.).

NB : In the first instance, these indicators are calculated for each growing year, to provide an idea of the performance of each crop. However, it should be noted that interpreting these indicators per year is not always pertinent.
Secondly, the average for the entire crop sequence is calculated, making it possible to compare rotations of different lengths.

The list of indicators can be found below, along with the calculation methods, input data and the parameter settings needed for the calculations.
Pages describing each indicator, their calculation methods and the hypotheses made in the calculator are available in the following pages.

Table 1: Indicators, calculation method, input data and parameters
In grey, indicators not calculated by the calculator offered with this guide.

Indicator	Calculation method	Data for input	Parameter data		Output
	n=length of rotation	Data	Data	Units	Output
TFI (calculated by the MAP calculator)	TFI crop= Σ [AD/R ×PT] for all commercial specialities used and for each treatment	Commercial speciality (CSP) Applied dose (AD) Proportion of field treated (PT)	Recommended dose (RD) by crop and by commercial speciality Source: MAP[a]	None	TFI total TFI herbicides TFI insecticides TFI fungicides TFI others
TFI	TFI/crop entered directly **or** TFI=pesticide costs/unit cost TFI for the crop TFIcs = Σ (TFIcrop)/n	TFI for each crop in the CS or pesticide cost for each crop	TFI unit cost per crop and per category of product (insecticides, herbicides etc.) Source: MAP[a]	€/TFI unit cost	TFI total TFI herbicides TFI insecticides TFI fungicides TFI others per crop and on average for the CS
Seed treatments	Number of crops with treated seeds/total number of crops	Use or not of treated seeds for each crop in the rotation			Frequency of use of treated seeds in the rotation

ANNEX 1 : INDICATORS USED FOR THE ENVIRONMENTAL EVALUATION OF CROPPING SYSTEMS

Indicator	Calculation method	Data for input	Parameter data		Output
	n=length of rotation	Data	Data	Units	Output
Energy costs	Σ (cost interv. i×nb interv. i)/n+number of units of N mineral input×energy cost of one unit+quantity of water given×energy cost for m^3 of water+energy cost of P for 1T of product×yield yield+energy cost of K for 1T of product×yield	Number of passages for: Rolling Ploughing Superficial cultivation Soil decompaction Sowing Hoeing /harrowing/rotary hoeing Mowing/maintenance Spreading manure/mineral fertiliser Spraying Harvesting Cutting/hay making/windrowing/baling Shredding Yields Quantities of water supplied Quantities of nitrogen supplied per crop N.B.: The number of passages can be directly reduced in the calculator according to the crop	Energy consumption/type of interventions Energy cost per unit of nitrogen Global needs of P and K per crop + energy cost per unit of P and K Energy cost per m^3 of water Sources: INRA, ADEME, 1999	MJ/ha MJ/T	Total energy cost per crop and average for the CS
Energy efficiency	Σ (NCV crop i/cost E crop i)/n		Net calorific value (NCV) of products and by-products Sources: INRA, ADEME, 1999		Energy efficiency per crop and average for CS
Bascule balance	Σ (N inputs-export coefficient×yield)/n	Quantity of nitrogen inputs in mineral or organic form Average yield per crop	Export coefficient per crop Source: COMIFER	kg N/ha	Nitrogen balance for the CS
Number and type of passages made		Number and type of passages made			Average number and type of passages in the CS
Gross product (GP)	Σ (yield×price)/n for all crops in the crop sequence	Average yield per crop	Sale price per crop	€/ha and €/q	Average gross product for the CS
Operational costs (OC)	Σ (quantity of seed purchased×price)+ Σ (TFI treatment i×unit cost of treatment i or phytosanitary charge)+ Σ (quantity of nitrogen inputs×unit cost of nitrogen)/n+cost of P for 1T of product×yield+cost of K for 1T of product×yield	Quantities of seed purchased per crop (in kg) TFI per crop and by type of treatment or plant protection product charges Quantities of fertiliser input per crop Quantities of organic nitrogen purchased Yields	Cost of seeds Cost of treatments/unit cost of TFI and by type of treatment Unit cost of N Global needs of P and K per crop+unit cost of P and K	Seeds: €/kg TFI: €/ha Mineral fertiliser (N/P/K): €/kg Organic fertiliser: €/kg	Average operational costs for the CS
Labour and machinery costs (LMC)	Σ (Number of interventions i×LMC for intervention i)/n	Number of passages for: Irrigation Soil decompaction Superficial cultivation Ploughing Sowing Spreading Spraying Harvesting Shredding Harrowing	Cost per type of intervention Source: Barèmes Entraide	€/ha	Average LMC for the CS
Direct margin	GP-OC-LMC			€/ha	Average direct margin for the CS
Purchase of specific equipment		Purchases to be made			
Learning costs		Number of new crops in the rotation Number of new practices in the crop sequence Number of new practices in the crop sequence			

ANNEX 1 : INDICATORS USED FOR THE ENVIRONMENTAL EVALUATION OF CROPPING SYSTEMS

TFI (TREATMENT FREQUENCY INDEX)

Source : MAP[a]

Calculated for :

- **Evaluation of the initial state**
- **Evaluation of the modified CS**

Objectives

TFI is a pressure indicator based on practices which can **measure the intensity of the recourse to pesticides in the rotation.** It makes it possible to verify if the candidate cropping system is indeed less reliant on pesticides than the initial system.
To evaluate the CS being studied, we position each crop according to the regional references used in the MAE plant protection products scheme.

Calculation method

TFI corresponds to the number of recommended doses of pesticides applied in a field during a growing season.
The TFI of a field is also a sum of the standard quantities of products for all the treatments (T) made in the field:

$$\boxed{TFI_{field} = \Sigma_T\ [AD_T/RD_T \times PF_T]}$$

with:
- AD_T the dose of a commercial product actually applied per hectare for treatment T
- RD_T the recommended dose per hectare of a commercial product for treatment T
- PF_T the proportion of the field treated during the treatment T.

This indicator is calculated by type of product (herbicides, fungicides, insecticides and other products) for each crop, thus providing an overall picture. We then calculate a TFI which corresponds to the cropping system in its entirety.

In the calculator we do not offer a tool for calculating TFI; for this we refer to the calculator offered by MAP[a].
In addition, according to the information available on the farm, the user can directly input the TFI or complete the level of pesticides. The parameters for the unit cost of the TFI for each category of products and for each crop have been set and allow us to obtain values close to the real TFI of the farmer.

Parameter data/data to be collected on the farm

The applied dose and the proportion of the field treated are indicated by the farmer during the description of his treatment programme. We must not forget to include those treatments made during the fallow period in the calculation.

Calculation methods for the evaluation of the modified CS

We describe beforehand the intervention programme. When we do not know which products will be used, we base them on the local TFI for the crop in question, adapted according to the crop management plan introduced. Equally, we can take into account the anticipated frequency of use: for example, if we change the sowing date for wheat, we reduce the risk of attack by autumn aphids. We could, therefore, decide to treat only one year in five. In this case, we note this in the calculator by marking a TFI of 0.2 rather than 1.
To help calculate TFI, a description of different CMP according to level of integration for various crops is provided in Annex 2.

[1] The recommended dose is the effective dose for an application of a product for a crop and for a target pest.

Limits
TFI is a measure of **the intensity of pesticide use** but does not describe the risk this represents for the environment (it does not take into account some characteristics of the products - such as toxicity or persistence - nor those of the environment in which they are used). Consequently, we could initiate a discussion during the evaluation on the choice of pesticides.

Complementary indicator in the calculator for seed treatments
TFI does not take into account seed treatments, so we complete the information by marking the percentage of treated seeds in the total number of seeds used by the farmer. We can also indicate if the farmer chooses treated seed or if the choice is that of the seed producer.

ENERGY CONSUMPTION

Source : ADEME, M. Cariolle (ITB)

Calculated for :
- **Evaluation of the initial state**
- **Evaluation of the modified CS**

Objectives
The aim is to estimate variations in energy consumption following changes in practices.

Calculation method
Here we use the conversion table offered by ADEME and M. Cariolle to estimate energy consumption for the following interventions (cf. section 'Number and type of passages made') :

- Rolling
- Ploughing
- Superficial cultivation
- Soil decompaction
- Sowing
- Hoeing/harrowing/rotary hoeing
- Mowing/maintenance
- Spreading manure/mineral fertiliser
- Spraying
- Harvesting
- Cutting/hay making/windrowing/baling
- Shredding

We can also take into account energy costs linked to the consumption of fertilisers and water.
To simplify the calculation, we consider only three types of fertiliser: ammonium nitrate for nitrogen, Super 45 for phosphorous and potassium chloride for potassium. Further, we consider that phosphorous and potassium will be adjusted according to the crop's needs.
We then calculate the energy costs for each crop, for each system and then the difference in consumption between the different systems.
Attention : For combined operations (for example, superficial cultivation and rolling), count these as only one operation.

Parameter data/Data to be collected on the farm
Data to be collected: number and type of passages made, quantities of nitrogen inputs, yields.
Parameter data: energy consumption for each type of intervention.

Limits
This indicator is based on the principal of saving energy: it makes it possible to reduce overall energy consumption, without taking into account the system's productivity. It should therefore be completed by the 'energy efficiency' indicator described below.

ANNEX 1 : INDICATORS USED FOR THE ENVIRONMENTAL EVALUATION OF CROPPING SYSTEMS

ENERGY EFFICIENCY OF THE SYSTEM

Source: ADEME, M. Cariolle (ITB)

Calculated for :
- **Evaluation of the initial state**
- **Evaluation of the modified CS**

Objectives
The aim is to estimate the system's energy efficiency by measuring the ratio between energy costs and the system's productivity.

Calculation method

Energy efficiency crop i=(CV crop i/E cost crop i)

with:
- CV crop i = calorific value of products
- E cost crop i = energy cost of the crop i

This indicator is calculated for all the crops, and then for the CS under study.

Parameter data/data to be collected on the farm
Data to be collected: number and type of passages made, quantities of nitrogen inputs, yields.
Parameter data: energy consumption for each type of intervention, calorific value for products.

Limits
This indicator evaluates the efficiency of the system: we are seeking here to optimise energy use without taking into account the fact that this resource may be limited. It should therefore be completed by taking into account the indicator 'energy consumption'.

BASCULE BALANCE

Source: Benoit M., 1992. Un indicateur des risques de pollution azotée nommé « BASCULE». (Balance Azotée Spatialisée des systèmes de Culture de l'Exploitation, (spatialized nitrogen balance for farm cropping systems)). Fourrages, 129, 95-110.

Calculated for:
- **Evaluation of the initial state**
- **Evaluation of the modified CS**

Objectives
The aim is to estimate the impact of the management of nitrogen fertilisation in zones where nitrogen is a major issue.

Calculation method and source of data
For the whole CS:

Balance = nitrogen inputs - nitrogen exports

with:
- Nitrogen inputs: total quantity of nitrogen brought to the field in mineral or organic form
- Nitrogen exports: total quantity of nitrogen exported by the production=average yield per crop x export coefficient of crop

Parameter data/data to be collected on the farm
Data to be collected: quantities of nitrogen inputs and average yield for each crop.
Parameter data : export coefficients per crop.

Calculation methods for the evaluation of modified CS
Nitrogen inputs are estimated for the newly introduced crops and average regional yields are used for the calculations.

Limits
This indicator should not be interpreted annually. Indeed, depending on the crop, good management of nitrogen inputs will not produce the same values for this indicator.
Oilseed rape is an important balancing mechanism and can surpass 50 kg/ha. Sunflower has a weak balancing effect (-10 kg/ha). Other crops have a balance ranging from 20 to 40 kg/ha.
This is explained by the fact that the calculation of the balance is based on exports and does not take into account potential returns to the soil. Neither does it take into account the characteristics of the environment, while the 'rational' management of inputs takes these factors into account. Furthermore, the Bascule balance takes into account all the inputs in organic form and not only the proportion of nitrogen which is effective during the growing season for a given crop. Neither is the symbiotic fixation of nitrogen by leguminous plants taken into consideration.
Finally, it should be noted that the balance does not take into account the management of nitrogen during the fallow period: we consider that all the nitrogen used by nitrate-fixing catch crops is returned to the soil.

NUMBER AND TYPE OF PASSAGES MADE

Calculated for :
- **Evaluation of the initial state**
- **Evaluation of the modified CS**

Objectives
The aim is to estimate the workload necessary to conduct all the interventions listed in the CMP.
This indicator makes it possible to judge the intensity of interventions in the CS.

Calculation method and sources of data
We count the number of passages conducted for the work listed below for the whole cropping system, according to the farmer, starting with the original state and for an a priori evaluation of the alternative CS:

- Rolling
- Ploughing
- Superficial cultivation
- Soil decompaction
- Sowing
- Hoeing/harrowing/rotary hoeing
- Mowing/maintenance
- Spreading manure/mineral fertiliser
- Spraying
- Harvesting
- Cutting/hay making/windrowing/baling
- Shredding

Attention : For combined operations (for example, superficial cultivation and rolling), count these as only one operation.

Limits
This indicator does not take into account possible conflicts in the work to be completed, which should be considered elsewhere in the design process, notably in using the table in support sheet S2 for the scheduling of work.

ANNEX 1 : INDICATORS USED FOR THE ENVIRONMENTAL EVALUATION OF CROPPING SYSTEMS

DIRECT MARGIN (DM) – CALCULATED FOR THE EVALUATION OF THE CURRENT CS

Objectives

This indicator is estimated for the current cropping system in order to then evaluate the effects of changes in practices on the margin.

Calculation method and source of data

- **Gross product**

For each crop, we use the following formula to calculate the gross product:

Gross product (GP) = yield × price

For the yield, we take the average yields of the farmer for the past five years.
The prices are the average selling prices for each crop.

Data to be collected: yields per crop
Parameter data: average selling price per crop

- **Operational costs (OC) and labour and machinery costs (LMC)**

For each crop, we calculate the operational costs, which take into account the cost of seeds and fertilisers based on the graphs supplied. To simplify the calculation, we consider only three types of fertiliser: ammonium nitrate for nitrogen, Super 45 for phosphorous and potassium chloride for potassium. Further, we consider that phosphorous and potassium will be adjusted according to the crop's needs.
Furthermore, different price contexts are offered in the calculator making it possible to conduct simulations of changes in the performances of systems in different economic contexts.
We estimate the cost of pesticides based on the TFI for each crop and for each type of product. For this we build on the calculation of the average TFI unit cost per crop and per category of product carried out in the ECOPHYTO programme.
The costs of mechanisation (price/hectares to be covered) and for labour are estimated with the aid of the tables offered by CUMA/Entraide.

Data to be collected: quantities bought, number and type of passages (cf. sheet 'Number and type of passages made').
Parameter data: costs of different products; price/ha for mechanised tasks and labour cost by type of intervention.

- **Direct margin**

DM = GP - OC - LMC

DIRECT MARGIN (DM) – CALCULATED FOR THE ALTERNATIVE CS

Objectives

This indicator is calculated for the ex ante evaluation of CS[a]. Hypotheses are made on the yields of crops grown according to the new CMP, or new crops introduced. The evolution of the direct margin is calculated **for the entire CS[a]** according to these hypotheses, **in the same price context** as the current CS[a].
We can then vary these hypotheses in the calculation to simulate different situations. Different price contexts, corresponding to 2006 (average prices), 2007 (high prices) and 2008 (low prices) are available in the calculator.

Calculation method and source of data

For the calculation, we proceed as follows:

Calculation of gross product

- Hypotheses are made both for the yields of newly introduced crops and on yields of crops whose growing method has been modified.
- At this stage, the price context is considered to be identical to that of the CS.

Data to be collected: yields

Data parameter: sale price per crop

Calculation of costs

Identical for the current CS, making hypotheses on the number of passages and the quantities of inputs involved.

Data to be collected/estimated: quantities bought, nature and type of passages made (cf. page 'Number and type of passages made').

Parameter data: price/ha for mechanised tasks and labour cost

Calculation of direct margin

$$\boxed{DM = GP - OC - LMC}$$

Limits

Labour costs are considered proportional to the number of passages made, though this is not the case in reality.

Also, possible investments necessary for the introduction of new practices are not taken into account, hence the indicator 'Purchase of specific equipment'.

Furthermore, other fixed costs are not taken into account here.

Finally, we do not take into account variations stemming from changes in direct subsidies, possible agro-environmental schemes etc.

The two indicators which follow are not calculated in the calculator which accompanies this guide. Nevertheless, it can be interesting to calculate them to complete the evaluation.

PURCHASE OF SPECIFIC MATERIAL

Calculated for :

- **Evaluation of the modified CS**

Objectives

This indicator seeks to complete the results for the indicator 'margin for economic manoeuvre'.

Calculation method and source of data

Based on the list of equipment available to the farmer and his cooperative, we can see which purchases are necessary and at what approximate cost: is the purchase possible for the farm and under what conditions ?

LEARNING COSTS

Calculated for :
- **Evaluation of the modified CS**

Objectives
If a farmer introduces new practices he may have undergo further training. This indicator seeks to measure the investment necessary.

Calculation method and source of data
Learning costs can be evaluated according to the following criteria:
- Number of new crops for the farmer
- Number of new practices (for habitual crops and for new crops)

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP^g SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Source: INRA, 2009, ECOPHYTO R&D, Vers des systèmes de culture économes en produits phytosanitaires. Volet 1, Tome II : Analyse comparative de différents systèmes en grande culture.

The CMP^g presented here are to help users in the reflection process and should never be considered as a standard formula to be applied as they are, no matter what the context. The results obtained can vary according to the production situation.

The logics used here are defined as follows:

- **'Integrated' logic:** the logic driving this system seeks to rationalise as much as possible the use of inputs while not changing the system.
- **'Integrated at the CMP scale' logic:** the logic behind this system is to modify the CMP of crops with a view to reducing the use of inputs but without changing the rotation.
- **'Integrated at the CS scale' logic:** the logic here is to modify both the CMP and the rotation with the aim of reducing the use of inputs.

COMMON (BREAD) WHEAT

Principles of the 'integrated' level

The control techniques and avoidance strategies used at this level concentrate in particular on rationalising chemical treatments. Using a better characterisation of risk based on agronomic criteria, supported by observations in the field, means the decision whether to treat or not can be based on risk thresholds. The impact of climate is taken into account through the use of epidemiological modelling, either directly or through official recommendations. The characterisation of risk, disease by disease, makes it possible to adapt the choice of fungicide and dose used, taking into account resistance risks attached to the frequency of use of the same product and/or reduced doses. Preventive seed treatments are used depending on the exposure to risk in the field.

Principles of the 'integrated at the CMP scale' level

This level is distinguished from the previous one by the application of agronomic management principles which mark a real 'break' in the practices and references used. It is not a case of further improving the rationalising introduced by using thresholds and DSS, but to really change, in a more or less profound way, the characteristics of the crop in order to reduce the risk of pest development and to reduce their consequences in terms of production and quality.

For common wheat, these principles rely in particular on:

- Delaying the sowing date by at least 15 days compared to 'current' practice
- Choosing multi-resistant varieties ('hardy') or using mixed varieties. In the future we could also take into account the necessity of genetic diversity at the regional scale
- Reducing sowing density (by 30-40% compared to the density recommended at the first level) and nitrogen dose through cancelling fertilisation at the tillering stage (consistent with the objective of a slightly lower yield)
- Shredding and burying of volunteers or crop residues which are hosts to pathogens
- Increasing the number of passages with superficial cultivation tools during the fallow period, with the aim of germinating non-dormant weed seeds on the surface and destroying shooting plantlets
- The introduction of mechanical weeding (using a spiked harrow or rotary hoe). However, there is no reasonable prospect of using this technique every year as it demands dry weather conditions at the right moment (one to three leaves minimum for the wheat depending on the type of tool), and with the weeds still at the cotyledon-plantlet stage.

By introducing this set of principles we can produce a crop canopy which is less favourable (aerated cover and less luxuriant) to the development of the principle diseases affecting common wheat. This efficacy is reinforced by the multi-resistant characteristics of the variety. The risk of lodging is also much reduced. Finally, delaying the sowing date makes it possible, in most cases, to avoid aphids which are vectors of BYDV and to reduce the germination potential of weeds, especially if superficial cultivation has stimulated the germination of seeds during the fallow period (the stale or false seed bed effect).

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

The combination of the proposed techniques at the scale of the crop management plan to manage weed flora (stale seed beds, later sowing date, mechanical weeding when possible) should make it possible to reduce herbicide use, though the scale is difficult to quantify because there are almost no references available (the majority of trials at the crop management plan scale do not consider the impacts on weed flora and weeding because of the multi-year dimension of the management of these pests). At this scale, the dependence on herbicides remains higher than in the following level which benefits from the effects of modified rotations to ensure the long-term management of weed infestations. The values of the TFI[g] for herbicide offered in the table which follows have been defined through a consensus of experts in the ECOPHYTO working group.

Principles of the 'integrated at the cropping system' level

At this level, the set of agronomic levers available is used with the aim of creating, at the annual scale, a crop status which is very unfavourable for the development of pests (see previous level) and, in the longer term, a reduction in the 'reservoir' of pests (weed seed bank through diversifying the rotation, disease inoculum through diversifying crops over space and time etc.) in the field and, indirectly, in neighbouring fields. This makes it possible to achieve a greater reduction in herbicide use than the previous level. The diversity of crops can be achieved by reconsidering the rotations, introducing crops other than wheat, notably oilseed and protein crops and beet. This also has positive effects on the soil's physical and chemical fertility.

Diversifying the rotation also makes it possible to diversify sowing dates; sowing dates can be delayed by at least three weeks for wheat or triticale. We can also choose competitive varieties (but not necessarily the most productive), create stale seed beds during the fallow period (numerous passages with shallow tools) and mechanical weeding. The combination of these techniques tends to reduce yields (up to 20 % lower according to trials on Integrated Protection for weeds, which maximises the use of these tools). However, wheat in systems at this level are never 'second' wheat, and therefore are not affected by the average yield penalty of 10 % observed in second wheat in intensive systems (and in the 'integrated at the CMP[g] scale' too). For these reasons, the agronomic performance (yield) of common wheat grown in this system is considered to be the equivalent of wheat grown in an 'integrated at the CMP[g] scale' system.

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – Common wheat

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	81	Slightly inferior to intensive CS	73	-9 %/integrated on average (from -5 to -20 %)	73	-9 %/integrated on average (from -5 to -20 %)
TFI total	4.9	Expertise/CA[a] advice	2.6		2.1	
TFI herbicides	1.8	1 autumn weeding 2 years in 3 and systematic spring remedial treatment	1.4	1 autumn treatment 1 year in 4 and 1 spring chemical Mechanical weeding 1 year in 2 (effect of sowing date)	1.2	1 spring treatment and 1 possible remedial (non-ploughing)
TFI fungicides	1.6	2 passages at 0.5 or 0.6 TFI and a third passage 1 year in 3	0.8	1 treatment at 80 % dose (late sowing, choice of variety, N reduced)	0.6	1 treatment from half-dose to 80 % depending on year
TFI insecticides	0.6	1 autumn insecticide 1 year in 3 + 1 spring insecticide 1 year in 2 to 4	0.2	1 insecticide 2 years in 10 (effect of sowing date and rationale in spring)	0.2	1 insecticide 2 years in 10 (effect of sowing date and rationale in spring)
TFI other	0.9	1 regulator 1 year in 2 according to region and 1 anti-slug 1 year in 6	0.2	No regulator except in mild winters (effect of nitrogen and sowing date and density)	0.2	1 anti-slug 1 year in 10
No. passages	Ploughing : 0.6 Superficial cultivation: 2.3 Spraying: 5.5 Mineral fertiliser: 2.6 (161 N) Organic fertiliser: 0.1 Mechanical weeding: 0	Suppression of first nitrogen input 1 year in 2 (deep soils)	Ploughing : 0.6 Superficial cultivation: 2.9 Spraying: 3.1 Mineral fertiliser: 2.1 (158 N) Organic fertiliser: 0 Mechanical weeding: 0.5	Cancellation of first nitrogen input in 90% of cases Harrow 1 year in 2	Ploughing : 0.5 Superficial cultivation: 3.3 Spraying: 2.3 Mineral fertiliser: 2.9 (143 N) Organic fertiliser: 0.1 Mechanical weeding: 0.5	Ploughing before perennial precedent (lucerne) or potato Suppression of first nitrogen input in 90 % of cases Mechanical weeding 1 year in 2

Source: ECOPHYTO R&D – Zones Lower Normandy, Burgundy, Champagne-Ardenne, Upper Normandy, Ile-de-France, Nord-Pas de Calais, Picardy

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

HARD (DURUM) WHEAT

Principles of the 'integrated' level

Pests of hard wheat are the same as those of common wheat, but the sensitivity or adaptations of strains exists, notably for septorias (leaf spot) which are more aggressive on common wheat than hard wheat in France. Taking into account the similarity, the rationale for chemical interventions which characterise this level are identical to those described for common wheat.

As is the case for common wheat, in the absence of statistical data on the performance of 'integrated' practices, this level has been compiled based on advisers from the Chambers of Agriculture and local expertise on the frequencies of the appearance of major pests. The average yields provided are again very slightly inferior (averaging 1 to 2 q/ha) to those of conventional systems, to take into account the risk of occasional failures in this strategy, which is used on a limited scale in hard wheat.

Principles of the 'integrated at the CMP scale' level

As for common wheat, these principles rely in particular on:

- Delaying the sowing date by at least 15 days compared to 'current' practice
- Choosing multi-resistant varieties ('hardy') where they are available, taking into account genetic diversity at the regional scale
- Reducing sowing density and nitrogen dose (linked with the objective of a slightly lower yield)
- Shredding and burying of volunteers or crop residues which are hosts to pathogens
- Increasing the number of passages with superficial cultivation tools during the fallow period
- Mechanical weeding.

Introducing this set of principles produces a crop canopy which is aerated and less luxuriant, and therefore much less favourable to the development of the principal diseases affecting hard wheat, and its efficacy is reinforced by the multi-resistant characteristics of the variety used. The risk of lodging is also much reduced. Delaying the sowing date makes it possible, in most cases, to avoid aphids which are vectors of BYDV, and strategies for weed management employ stale seed beds. Mechanical weeding techniques (spiked harrow or rotary hoe) are also introduced at this level, despite their only average efficacy. Because of more favourable weather conditions in hard wheat production regions, mechanical weeding may be used every year, which is not the case for common wheat.

Principles of the 'integrated at the cropping system' level

At this level, the aim is to reduce the 'reservoir' of pests in the field and, indirectly, in nearby fields, by diversifying the rotation and/or the spatial arrangement of crops. A diversity of crops can be achieved by increasing the share of species other than hard wheat in the rotation and avoiding the succession of two hard wheat crops (on average, 42 % of hard wheat fields in the SCEES 2006 sample were preceded by wheat (common or hard), and this proportion was higher still in the PACA and Languedoc Roussillon regions of France). Diversifying the sowing periods reduces specialisation of the weed flora, making it easier to manage.

Even more so than for common wheat, experiences of the introduction of these strategies at the cropping system scale are rare; experts have used and developed the experience acquired in a few long-term experimental 'cropping systems' (the Arvalis experimental farm at Boigneville), and prototype work shared by cropping system experts involved in the ADAR project 'Systèmes de culture innovants' (innovative cropping systems).

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – hard wheat

The regions used here for the characterisation are Centre, Midi-Pyrénées, Pays de Loire and Poitou-Charentes.

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	55	Slightly inferior to intensive	50	-9 %/integrated (from -5 to -20 %)	50	-9 %/integrated (from -5 to -20 %)
TFI total	3.4	Expertise/ CA[a] advice	2.7		2.5	
TFI herbicides	1.4	1 mixed weeding end of winter + 1 remedial 1 year in 2	1.2	1 full dose spring treatment + 1 occasional remedial Mechanical weeding 1 year in 2	1	1 spring treatment Mechanical weeding 1 year in 2
TFI fungicides	1.3	2 treatments (foliar and ear) Obligatory Fusarium treatment 0.7	1	1 foliar treatment 1 year in 2 + 1 Fusarium treatment at 0.7	1	1 foliar treatment 1 year in 2 + 1 Fusarium treatment at 0.7
TFI insecticides	0.5	1 treatment 1 year in 2	0.3	1 treatment 1 year in 3	0.3	1 treatment 1 year in 3
TFI other	0.2	1 anti-slug 1 year in 5	0.2	1 anti-slug 1 year in 5	0.2	1 anti-slug 1 year in 5
No. passages	Ploughing: 0.5 Superficial cultivation: 2.3 Spraying: 4 Mineral fertiliser: 3.6 (191 N) Organic fertiliser: 0 Mechanical weeding: 0		Ploughing: 0.5 Superficial cultivation: 2.8 Spraying: 3.2 Mineral fertiliser: 3 (173 N) Organic fertiliser: 0 Mechanical weeding: 0.5		Ploughing: 0.25 Superficial cultivation: 2.8 Spraying: 3 Mineral fertiliser: 3 (173 N) Organic fertiliser: 0 Mechanical weeding: 0.5	

Source: ECOPHYTO R&D – Zones Centre, Midi-Pyrénées, Pays de Loire, Poitou-Charentes

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

SPRING BARLEY

Principles of the 'integrated' level

Current practice for growing spring barley seeks to maximise yields through establishing a high number of ears. This objective is currently reached by a high sowing density (the practices used for winter common wheat are also used for winter barley) and early inputs of nitrogen which, combined with the high tillering capacity of this species, contribute to a closed crop canopy. This tightly closed canopy maintains humidity and temperature levels which favour the development of fungal diseases (net blotch, Rhynchosporium, mildew, dwarf leaf rust and, more recently, lesions on the leaves associated with pollen and Ramularia). Research to identify threshold levels for fungicide treatments, based on the frequency of leaves affected at a given leaf stage, has not been completed. Similarly (and unlike the situation for wheat) there is a desperate lack of DSS to predict disease risk. The result is a rather systematic recommendation for the application of two fungicide treatments, the first of which may be adjusted if diseases appear later than usual or the variety is less susceptible to disease. The decision not to conduct the first treatment is left to the adviser or farmer, with no objective means of making this decision.

For both types of barley, the number of varieties tolerant to disease is limited. In fact, the choice of variety for two-row barley is imposed by the industry to meet the specifications of maltsters and brewers. Thus the technological quality takes priority over disease tolerance and lodging. Farmers and advisers therefore do not always have a choice in which variety to grow: choosing a variety which is not preferred by the sector excludes farmers from growing under contract, which is a priori, more remunerative. For feed barley, the choice of variety is more open.

Principles of the 'integrated at the CMP scale' level

The principles applied are based in particular on:

- Choosing less susceptible varieties (notably for net blotch and dwarf leaf rust), taking into account genetic diversity at the regional scale.
- Reducing sowing density (by at least 20% compared with the first level) and nitrogen inputs (linked with the objective of a slightly lower yield).
- Shredding and burying volunteers or crop residues which are host to pathogens.

The application of this set of principles produces a canopy which is aerated and less luxuriant, and therefore less favourable for the development of the principal diseases affecting barley. Its efficacy is reinforced by the lower susceptibility of the variety used. The risk of lodging is also much reduced. Mechanical weeding techniques (spiked harrow) are also introduced at this level.

The introduction of experimental systems for integrated crop management of barley is comparatively recent and not yet organised like that for common wheat. Also, the characterisation at this level relies on the expertise of its members, expanded with 'resource' people for this crop (a few trials in the 'hardy wheat' network since 2006).

Principles of the 'integrated at the cropping system' level

At this level, the aim is to reduce the 'reservoir' of pests present in the field and, indirectly, in nearby fields, by diversifying the rotation and/or the spatial arrangement of crops. A diversity of crops can be obtained by increasing the share of species other than barley in the rotation. This helps reduce the weed flora in the system; the diversification in crops is accompanied by a diversification in sowing dates and makes weed management easier.

Even more so than in the previous level, experiences of the introduction of these strategies at the cropping system scale are rare; experts have used and developed the experience acquired in a few long-term experimental 'cropping systems' (PIC weeds at INRA in Dijon, the Arvalis experimental farm at Boigneville), and prototype work shared by cropping system experts involved in the ADAR project 'Systèmes de culture innovants' (innovative cropping systems).

Performance of different systems and justification for the practices introduced – spring barley

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	62	1 to 2 % less than level 0	56	-9 %/integrated	56	-9 %/integrated
TFI total	3.95	Expertise/ CA[a] advice	2.65		2.15	
TFI herbicides	1.6	1 base IPU* full dose + 1 possible remedial at reduced dose Ref. 'to be chosen'	1.3	1 anti-dicotyledons + 1 glyphosate 1 year in 2 0 to 2 spiked harrow	0.8	Crop sequence => less infestation + mechanical weeding. Lower remedial frequence
TFI fungicides	1.5	Regional difference in strength and virulence of pest complex	0.75	Choice of variety + N reduced + no over-density	0.75	Choice of variety + N reduced + no over-density
TFI insecticides	0.15		0.1	1 insecticide 1 year in 10	0.1	1 insecticide 1 year in 10
TFI other	0.7	1 regulator for deep soils, 0 for shallow soils + 1 quasi systematic treatment to reduce broken collar on ear	0.5	1 anti-slug 1 year in 5	0.5	1 anti-slug 1 year in 5
No. passages	Ploughing: 0.7 Superficial cultivation: 2.3 Spraying: 5.1 Mineral fertiliser: 1.8 (125 N) Organic fertiliser: 0.1 Mechanical weeding: 0		loughing: 0.6 Superficial cultivation: 3.3 Spraying: 3.4 Mineral fertiliser: 1.5 (113 N) Organic fertiliser: 0.1 Mechanical weeding: 1	0 to 2 harrows	Ploughing: 0.6 Superficial cultivation: 3.3 Spraying: 2.8 Mineral fertiliser: 1.5 (113 N) Organic fertiliser: 0.1 Mechanical weeding: 2	2 harrows

Source: ECOPHYTO R&D – Zones Centre, Midi-Pyrénées, Pays de Loire, Poitou-Charentes

*IPU : isoproturon

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

WINTER BARLEY

The same principles for spring barley.

Performance of different systems and justification for the practices introduced – winter barley

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	70	1 to 2 % less than level 0	64	-9 %/integrated	64	-9 %/integrated
TFI total	3.4	Expertise/ CA[a] advice	2.3		2.1	
TFI herbicides	1.5	1 systematic autumn root treatment + 1 remedial anti-gramineae or anti-dicotyledons at the end of winter if needed	1.2	Choice of competitive variety Spiked harrow + FOP or SH hormone	1	1 anti-dicotyledons at half dose + 1 anti-gramineae 1 year in 2 + harrow
TFI fungicides	1.5	2 treatments at 75 % dose	0.8	Choice of variety + late sowing + reduced N	0.8	Choice of variety + late sowing + reduced N
TFI insecticides	0.1	No insecticide (Gaucho treatment of seeds) + insecticide 1 year in 10	0.1	1 insecticide 1 year in 10	0.1	1 insecticide 1 year in 10
TFI other	0.3	Treatment to reduce broken collar on ear in certain years + occasional regulator	0.2	Treatment to reduce broken collar on ear in certain years	0.2	Treatment to reduce broken collar on ear in certain years
No. passages	Ploughing: 0.7 Superficial cultivation: 2.3 Spraying: 4 Mineral fertiliser: 2.5 (138 N) Organic fertiliser: 0.1 Mechanical weeding: 0		Ploughing: 0.5 Superficial cultivation: 2.8 Spraying: 2.7 Mineral fertiliser: 1.8 (123 N) Organic fertiliser: 0.1 Mechanical weeding: 1		Ploughing: 0.5 Superficial cultivation: 3.3 Spraying: 2.5 Mineral fertiliser: 1.8 (123 N) Organic fertiliser: 0.1 Mechanical weeding: 1	1 harrow

Source: ECOPHYTO R&D – Zones Burgundy, Brittany, Centre, Champagne, Franche-Comté, Ile-de-France, Lorraine, Poitou-Charentes

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

OILSEED RAPE

Principles of the 'integrated' level

The control techniques and avoidance strategies used at this level rely in particular on rationalising chemical interventions. The use of observations/traps and/or epidemiological modelling (through the use of official recommendations) means the decision to treat or not can be based on thresholds, or even adapting the dose. Against sclerotinia, fungicide treatments are preventive, but are triggered taking into account an estimation of the infectious potential of the field and weather forecasts.

Weeding in oilseed rape is challenging because of the evolution in the flora which becomes difficult to control because of the lack of satisfactory chemical or agronomic solutions. An increase of flora rich in geranium and cruciferous weeds is a problem with the frequent return of oilseed rape to the rotation. The battle to control parasitic broomrape in western France and the management of cruciferous weeds remain pest problems which can not always be resolved because of the lack of adequate herbicides (plants tolerant to glyphosate or ALS* inhibitors). These pests make it necessary to lengthen rotations, including systems using integrated practices.

Principles of the 'integrated at the CMP scale' level

Work on crop management plans for winter rape was launched in the mid 1990s by INRA and Cetiom. This has provided the basis for strategies contributing to limiting pesticide use in this crop. An experimental network, the results of which form the basis of this section, was established. It has involved, since sowing in 2004 through to the harvest of 2008 (therefore four years of experiments), INRA, France's Chambers of Agriculture and Cetiom.

The principles introduced for winter rape are based on the crop smothering weeds (perhaps combined with mechanical weeding) and avoiding animal pests and diseases.

Smothering **weeds** is conceivable because rape crops have a high autumn growth capacity. It therefore seems possible to sufficiently limit weed growth so they do not affect the yield of rape seeds, and to ensure weed seed production does not increase the seed bank in the field. This autumn growth capacity can be achieved provided that sowing is early and there is sufficient nitrogen available in the soil. The environment should be capable of supplying around 120 kg of nitrogen between sowing and the start of winter (Valantin-Morison and Meynard, 2008). When growing in shallow, stony soils (such as those in Poitou-Charentes, Bourgogne and Lorraine) these situations are rare without nitrogen inputs from outside the system. Nevertheless, arable zones do exist where soils are suitable for this growth and where the objective can largely be reached, such as Picardy, Brittany, Eure et Loir and Normandy. The success of the smothering strategy depends equally on the type of weeds and tillage. Summer nitrophilous species also benefit from early sowing and high nitrogen availability. The development of these weeds will therefore be greater in the absence of ploughing and competition from oilseed rape if repeated and shallow stubble ploughing is not conducted to destroy shoots and weeds.

In situations where oilseed rape cannot smother weeds (late sowing and/or low nitrogen availability), mechanical weeding may be used. Here it replaces here a post-emergence remedial chemical treatment. Equally, it can be used as a complement to the smothering strategy for controlling nitrophilous summer species. The introduction of mechanical weeding means oilseed rape must be sown in widely spaced rows (> 24 cm).

Avoiding **autumn animal pests** can also be achieved through modifying the sowing date. Early sowing (15 days before the recommended date in the region) avoids some autumn insects (cabbage stem flea beetles and sawflies), as well as slug attacks (Valantin-Morison et al., 2007).

The majority of the work on **spring insects** concerns pollen beetles. Currently, alternatives to chemical control for these pests appear to be insufficiently effective. The techniques they use, based on avoidance or using 'trap flowers', have only very partial efficacy and quickly become insufficient when there is average to high pest pressure (an upsurge has been reported in numerous French regions in recent years). These difficulties explain the very small proportion of fields dedicated to oilseed rape in organic farming systems.

* ALS : acetolactase synthase

Avoiding **diseases** is a strategy which provides ambivalent results for the control of phoma. Early sowing helps in avoiding this disease in numerous situations (Aubertot et al., 2005; Valantin-Morison, 2007), but strong growth, linked to high nitrogen availability, can favour phoma (Aubertot et al., 2005). The hypothesis put forward is two-fold: (1) high nitrogen availability in the environment linked with early sowing causes an elongation of the stem before winter, making the plant more susceptible to frost and leaving the door open to disease development; (2) the plant's surface area is greater, so the probability of contamination with phoma is therefore raised. Concerning phoma, advancing the sowing date means that a variety which has low or very low susceptibility must be used.

Principles of the 'integrated at the CS scale' level

The principles used are those found in integrated production.

The application of these principles produces rotations which are different to most of those found today because there is a larger diversity of crops, linked with long periods before the return of crops which are host to the same telluric pathogen (oilseed rape and other crops susceptible to sclerotina). Consequently, we have chosen to manage disease risk only through biological control (the application of Contans). Other measures such as burying crop residues to limit contamination (phoma, pollen beetles) only have real efficacy if they are introduced on a regional scale.

For these reasons, and despite the reduction in the frequency of the return of oilseed rape (and, on a larger scale, the regional proportion of oilseed rape), oilseed rape yields in this type of system will be lower than crops grown in a system 'integrated at the CMP scale' because of the raised disease risk.

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – oilseed rape

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	29.3	-2 q compared to intensive	26.6	0 to 10 q loss compared to intensive (-30 % loss 1 year in 2, identical 1 year in 2), -15 %/ intensive	25.3	-5 % compared to integrated at CMP scale (increased risk of diseases)
TFI total	6	Expertise/ CA[a] advice	4.2		2.95	
TFI herbicides	1.5	1 autumn weeding + 1 post weeding (anti-gramineae or anti-dicotyledons) 1 year in 3	1.2	Smothering strategy + 1 reduced dose pre or post early sowing + chemical complement	0.75	Mechanical weeding (hoeing) + chemical at ¾ dose
TFI fungicides	1.2	1 sclerotina treatment maybe renewed 1 year in 4 to 2 years in 5	0.8	1 systematic treatment at 80 %	0	Contans in the crop sequence (calculated at 3 crops at 2 kg then 1 then 1)
TFI insecticides	2.7	1 autumn treatment (flea beetle) 1 year in 3 to 4 years in 5 + 2 spring treatments (blossom beetle, stem weevils) + third spring treatment 1 year in 4 (pod weevils, blossom beetle)	2	Insecticides against stem weevils and Bt, trap flowers for blossom beetle, rape (early sowing avoids flies, cabbage stem flea beetle)	2	Insecticides against stem weevils and Bt, trap flowers for blossom beetle, rape (early sowing avoids flies, cabbage stem flea beetle)
TFI other	0.6	1 anti-slug 3 years in 4 to 5. One regulator for susceptible varieties 1 year in 3	0.2	No regulator. Anti-slug avoided by early sowing (1 treatment 1 year in 5)	0.2	Anti-slug 1 year in 5
No. passages	Ploughing: 0.5 Superficial cultivation: 2.6 Spraying: 6.5 Mineral fertiliser: 2.5 (157 N) Organic fertiliser: 0.2 Mechanical weeding: 0		Ploughing: 0.5 Superficial cultivation: 2.6 Spraying: 4.5 Mineral fertiliser: 2.5 (139 N) Organic fertiliser: 0.2 Mechanical weeding: 0		Ploughing: 0.5 Superficial cultivation: 2.6 Spraying: 3.2 Mineral fertiliser: 2.5 (131 N) Organic fertiliser: 0.2 Mechanical weeding: 1.8	1 harrowing, 1 hoeing 4 years in 5

Source: ECOPHYTO R&D - Zones Ile-de-France and Picardy

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

GRAIN MAIZE

Principles of the 'integrated' level

The control and avoidance techniques used concern only **animal pests** and are based in particular on rationalising chemical treatments. For one set of pests (European and Mediterranean corn borers), the use of a better characterisation of risk based on agronomic criteria, accompanied by observations, means the decision on whether to treat or not can be taken according to risk thresholds. This has an indirect effect on Fusarium by avoiding injuries which could be entry points for disease in the cob. The impact of climate is taken into account through epidemiological modelling (directly or through official recommendations). Treatment of seeds or in the seed row (against frit fly and click beetle), a preventive measure, is used according to the level of risk in the field.

Concerning **weeding**, employing strategies post-emergence (at the seven leaf stage) is a priori tempting at this level because it allows for better rationalising of treatments according to the type of flora and adjustment of doses, but its efficacy is highly dependent on the stage of weed development and humidity and temperature levels. Therefore two passages may be necessary if conditions dictate. Another intermediary variant uses a root treatment rather than a foliar treatment for gramineae weeds at an early post-emergence stage (towards two to three leaves). In all cases, the reduction in dependence on herbicides, as measured by the TFI, remains very limited at the 'integrated' level.

Principles of the 'integrated at the CMP scale' level

Selection of an appropriate variety provides adequate control for the principal maize diseases.

Concerning **animal pests**, sowing techniques which encourage rooting and speed of growth are preferred (avoiding early sowing and use of starter fertiliser) where there is a risk of click beetle or frit fly injury. However, early sowing is the preferred tactic in zones where Mediterranean corn borer or two generations of European corn borer are a threat. Trichogramma are used for the control of European corn borer.

At this level, efforts rest essentially on reducing the use of herbicides. The alternative solutions to herbicides for **weed** management are the same as those developed for sunflower: they make use of hoeing alone or a combination of chemical control plus successive or simultaneous mechanical weeding (mixed weeding). The objective is to obtain a weeding quality comparable to chemical control without any loss in maize yield. Agronomic benefits are expected in certain conditions, such as breaking the soil crust and soil aeration.

Several strategies are possible for mixed weeding (mechanical plus chemical):

- Mechanical (spike harrow or rotary hoe) then chemical (remedial with the dose adjusted to the stage of the weeds present at the five to six leaf stage of the maize)
- Chemical (with the dose adjusted for three leaves) then mechanical (hoe, at six to eight leaves)
- Weeding through a combination of precision spraying and hoeing (three to four leaves) then hoeing (seven to eight leaves)
- Pre-emergence treatment of the row (seed drill equipped with spraying equipment) then one or two hoes.

These strategies can reduce doses by 50 to 70% compared to an 'all chemical' approach. They are accompanied by a potential yield loss estimated at 0 to 6% compared to intensive production, linked to the depressive effects of the spike harrow on young maize, which can cause plant losses after repeated passes of mechanical weeding. Mechanical interventions are highly dependant on weather conditions.

It must be noted, however, that the rise in fuel costs makes mechanical weeding less attractive to farmers.

Principles of the 'integrated at the CS scale' level

Compared with the previous level, breaking the cycle of monocropping and the adoption of more complex rotations diversifies and reduces the competitiveness of weed flora. This is particularly so in irrigated zones such as south-west France, where soya, sunflower and wheat can break the monocropping cycle. This can further safeguard the efficacy of mixed weeding techniques. The adoption of more diversified rotations also limits pressure from Mediterranean and European corn borers (efficacy is reinforced by a really collective management effort).

Performance of different systems and justification for the practices introduced – grain maize

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	96.7	Identical to the 'intensive' level	90.9	-6 %/intensive (principally the effect of hoeing)	87	-10 %/intensive (late sowing)
TFI total	2.1	Expertise/ CA[a] advice	1.7		0.9	
TFI herbicides	1.5	1 weeding before sowing + 1 pre or post emergence + 1 remedial at reduced dose 1 year in 2 (accor-ding to weed pressure and success of pre-emergence)	1.1	Post emergence + hoeing	0.6	Weeding in the row + hoeing (crop sequence => no specialised flora)
TFI fungicides	0		0		0	
TFI insecticides	0.5	2 insecticides (European or Mediterranean corn borers) 1 year in 2 for 50 % of the field	0.5	Identical to first level	0.3	Crop sequence, shredding => low Mediterra-nean corn borer pressure + Trichogramma
TFI other	0.1	1 anti-slug 1 year in 3 for 1/3 of the field (humid soils)	0.1	Identical to first level	0	Very occasional
No. passages	Ploughing: 1 Superficial culti-vation: 2.1 Spraying: 2.4 Mineral fertiliser: 2.3 (177 N) Organic fertiliser: 0.2 Mechanical wee-ding: 0.3		Ploughing: 1 Superficial culti-vation: 2.7 Spraying:1.9 Mineral fertiliser: 2.3 (165 N) Organic fertiliser: 0.2 Mechanical wee-ding: 1	1 hoeing	Ploughing: 1 Superficial culti-vation: 3.5 Spraying: 1 Mineral fertiliser: 2.3 (156 N) Organic fertiliser: 0.2 Mechanical wee-ding: 2	2 hoeings

Source: ECOPHYTO R&D - Zones Burgundy, Rhône-Alpes, Centre, Auvergne, Alsace, Midi-Pyrénées, Poitou-Charentes, Aquitaine and Ile-de-France

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

SUNFLOWER

Principles of the 'integrated' level

The control and avoidance techniques used in the transition to the 'integrated' level rely essentially on more precisely rationalising the use of chemical interventions (fungicides and weed control).

Principles of the 'integrated at the CMP scale' level

Concerning **diseases,** the principles used rely on a combination of a choice of varieties which have very low susceptibility (VLS) or resistance to phomopsis.

In sunflower, we have a range of varietal tolerance to phomopsis and to sclerotinia which can be exploited more systematically without any loss in yields. The use of VLS varieties instead of those with low susceptibility (which are the varieties most commonly sown in French regions where phomopsis is present, contrary to the advice of Cetiom) makes it possible to halve the recourse to fungicide treatments. The use of resistant varieties (R) (low in number, and currently availability is low among the cooperatives) would be a means of totally stamping out its use.

Experimental results have also shown that rationing of the crop (no irrigation, limited nitrogen and reduced density of around 50-55,000 plants/ha instead of 60-65,000) coupled with a tolerant variety, makes it possible to avoid fungicide treatments in many situations (except for very wet years) (Debaeke et al., 2003). Later sowing, at the end of April/beginning of May (no effect on the risk of exposure to drought) instead of mid-April, reinforces the efficacy of such measures and can reduce the impact of premature drying caused by phoma.

To tackle **weeds**, the strategies used are based on techniques which help limit the seed bank and reduce the prevalent systematic use of pre-sowing and pre-emergence products through combinations of chemical and mechanical weeding.

Changing the sowing date makes it possible to create stale seed beds in spring, contributing to reducing weed pressure. This possibility is very interesting, notably for weeds which are difficult to destroy and therefore increase herbicide costs (such as ragweed). The pre-sowing and post-emergence programmes employed in the majority of systems today do not allow any adjustments for the real risk of contamination (potential flora but also germinated flora). Currently we do not have the possibility of substituting in a general way the pre-sowing treatment by a post-emergence one (this is only possible for gramineae weeds), and changes in the pre-emergence dose in situations of low infestation by classic flora remain dependent on drought in summer crops. However, an evolution is underway with the adoption of innovations which combine a change in variety and the probable authorisation of broad spectrum herbicides with ALS inhibitors. These herbicides help to control post-emergence those weeds which are currently difficult to control (ragweed, broomrape and wild Asteraceae).

In this context, the introduction of mechanical weeding may be reinforced with a view to reducing the use of herbicides: mixed weeding, combining treatment directed at full dose on the seed row and hoeing between the rows (at the three to five pairs of leaves stage). Spacing of 75-85 cm can make this practice easier but is not essential. Hoes equipped with a guidance system can increase the rate at which the work can be achieved (15 min/ha) without losing any precision (working within 5-10 cm of the row). The treatment of the row still uses pre-emergence products, but leads to a reduction in the TFI herbicide of **40 to 60 %**.

Relying on only hoeing (in two or three passages) is too dependent on climatic conditions and is not sufficiently effective for all types of flora to be suggested as a complete substitute for chemical weeding.

Principles of the 'integrated at the CS scale' level

The principles introduced for this level are those identified for the preceding level, to which are added a larger diversification of the rotation in which sunflowers are grown. This diversification (and its consequences at the regional scale) leads directly to a lower frequency in the return of sunflower to the field, helping to:

- Reduce the pressure from the principal diseases which persist through harvest residues or conservation organs (sclerotia). The introduction of Contans (biological control) is used only in situations where there is a raised level of inoculum
- Reduce certain weeds specific to the crop (or to improve control in other crops as a consequence of the diversification).

At this level we can also propose the introduction of regional management, in particular for the shredding and burying of harvest residues (reducing phoma inoculum), but ploughing after sunflower is little used on clay-limestone soils for the sowing of wheat.

Performance of different systems and justification for the practices introduced - sunflower

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	26.3	Intensive + ½ ET	22.7	Identical average	23.6	Identical to intensive
TFI total	2.7	Expertise/ CA[a] advice	1.2		1.1	
TFI herbicides	1.8	1 pre-sowing + 1 weeding at sowing (+ 1 anti-gram. rare (wild oats))	0.6	1 treatment seeds in the row at sowing + hoeing	0.6	1 treatment seeds in the row at sowing + hoeing
TFI fungicides	0.4	2 years in 5 (phomo/ phoma)	0.2	1 year in 5 (choice of variety)	0.1	1 year in 10 (rotation)
TFI insecticides	0.2	Maximum 1 year in 5	0.1	1 year in 10	0.1	
TFI other	0.3	1 anti-slug 1 year in 3	0.3	1 anti-slug 1 year in 3	0.3	Maybe anti-slug
No. passages	Ploughing: 0.9 Superficial cultivation: 2.2 Spraying: 3.1 Mineral fertiliser: 0.9 (53 N) Organic fertiliser: 0.1 Mechanical weeding: 0.3	Remedial 3 years in 10	Ploughing: 0.9 Superficial cultivation: 27 Spraying: 1.4 Mineral fertiliser: 0.5 (39 N) Organic fertiliser: 0.1 Mechanical weeding: 2	Stale seed beds Reduced/ rationalised (bottlenecks) 2 hoes + weeding kit for in the row (between 6 k€ and 20 k€)	Ploughing: 1 Superficial cultivation: 3.5 Spraying: 1.3 Mineral fertiliser: 0.5 (43 N) Organic fertiliser: 0.1 Mechanical weeding: 2	Stale seed beds Reduced/ rationalised (bottlenecks) 2 hoes + weeding kit for in the row (between 6 k€ and 20 k€)

Source: ECOPHYTO R&D - Zone France

POTATO

Principles of the 'integrated' level

The rationale rests principally on the management of diseases. Preventative fungicide treatments must be given in accordance with the development of disease in the crop; they are conducted taking into account an estimation of the infection potential of the field and weather forecasts (official recommendations).

The introduction of DSS (such as Mildi-LIS developed by ARVALIS* and MilPV developed by MAP[a], the two tools were expected to be combined in 2008) means we can avoid systematic protection of fields. Different parameters are taken into account: date of emergence, weather conditions, variety etc. The main block to the development of these tools is the necessity of working with local weather data; buying weather data or a weather station is essential to the functioning of these two DSS.

* Arvalis – Institut du végétal is the new name of ITCF[a] since few years.

Principles of the 'integrated at the CMP scale' level

The principles used are based on avoiding contamination of the field and choosing varieties less susceptible to diseases, linked with thresholds for the first treatment adapted to the level of resistance. Experimentation is regularly conducted to offer a ranking of varieties. However, varietal resistance is insufficient to constitute an effective strategy against blight. Of the 175 varieties available in the French Catalogue, only 64 have a score for resistance to blight which is higher than that of Bintje (scores 3 out of 9). The two types of resistance (leaf and tuber) have to be taken into account in the rationale for choosing the varieties because there is no proportionality between foliar and tuber attacks. Environmental conditions (regular humidity or alternating humid and dry periods) dictate the transmission of spores from leaves to tubers.

Prophylactic measures, notably the control of volunteers (in beet or cereal crops, for example) and the good management of piles of crop residues (burying or covering with plastic sheeting), can reduce primary sources of infection and delay the arrival of blight. Removing the tops of the plants (haulms) at the end of the growing period allows tubers to develop the impermeable skin which is necessary for good resistance to fungal diseases and viruses.

Choosing varieties which are less susceptible, sowing at sufficient depth, good earthing up and limiting excesses of nitrogen are the principal measures for limiting attacks and protecting tubers. The results can vary depending on the production site, soil and weather conditions, cropping history of the field and proportion of potato fields in the vicinity. However, choosing resistant varieties runs up against the possible breaking of this resistance, most often based on a single gene, by blight. Regular observation in the field can limit the risk of fungus developing in cases where resistance has been broken, but requires the anticipation of treatments if needs be.

It must, however, be remembered that currently producers rarely have the choice of which varieties to grow: the choice is very limited and generally imposed by the market. A variety's quality criteria (in the strict sense of the look of the tuber or in an industrial sense its suitability for processing) take priority over its agronomic characteristics.

Removing the haulms of potato plants is, essentially, a chemical procedure. It is conducted three weeks before harvesting in one or two passages. Alternatives to chemical removal have been examined. Thermal removal has been shown to be effective but is not used here because of its energy cost and contribution to the production of greenhouse gases. Mechanical removal, which consists of chopping the tops at maturity, is a technique that can be used providing nitrogen has been managed to avoid any excesses which could delay maturity.

Finally, alternative strategies to all-chemical weeding have been suggested. They consist of a combination of chemical weeding and earthing up: a first weeding is conducted early and then followed by one or two passages of combined weeding and earthing up (using the ridger as a mechanical weeding tool through the addition of tines). A final weeding is conducted during the final earthing up. These strategies have been tested by Agro-Transfert[a] in Picardy and have shown an efficacy comparable to an all-chemical strategy. However, the efficacy comparable with a chemical programme is highly dependent on the weather conditions (rain) in the post-mechanical weeding period and also increases the working hours required.

Principles of the 'integrated at the CS scale' level

Work on low-input systems for potatoes is rather old and low in number. The Institut Technique de la Pomme de terre (potato technical institute), in collaboration with ACTA[a], ITB[a] and ITCF[a], studied systems described as 'integrated' including potatoes between 1991 and 1994. Experimental field trials were established over 12 ha at the Centre d'Expérimentation et de Démonstration Nord-Picardie (the north Picardy centre for experimentation and demonstration) at Villers St Christophe (department of Aisne). But the reduction of inputs concerned only nitrogen due to the damaging potential of blight. Data concerning potato cropping methods with reduced reliance on pesticides within an overall integrated strategy have yet to be produced. Given this lack of experience, potato cropping at this level is very similar to that proposed in the previous one. The low frequency of potato in the rotation means we can hope that manual weeding will ensure satisfactory weed control.

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – potato

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	40	A little inferior to intensive CS	34	Loss in marketable yield -20 à 50 % (2 years in 10). On average -20 %/intensive	34	Loss in marketable yield -20 à 50 % (2 years in 10) On average -20 %/intensive
TFI total	16.7		12.6		11.6	
TFI herbicides	2.1		1	Combination of chemical at low doses (Sencoral type) and weeding/earthing up	0	All mechanical
TFI fungicides	13	2 to 6 treatments less than intensive, use of DSS (models)	11	Use of DSS with adapted thresholds + choice of variety with risk of broken resistance by blight	11	Use of DSS with adapted thresholds + choice of variety with risk of broken resistance by blight
TFI insecticides	0.6	Against aphids and Colorado beetle, as needed according to thresholds	0,6	Identical rationale, aphids and Colorado beetle (thresholds)	0.6	Identical rationale, aphids and Colorado beetle (thresholds)
TFI other	1	Chemical removal of haulms	0	Mechanical removal of haulms	0	Mechanical removal of haulms
No. passages	Ploughing: 1 Superficial cultivation: 3.5 Spraying: 16.5 Mineral fertiliser: 2.2 (150 N) Organic fertiliser: 0.4 Mechanical weeding: 0.1		Ploughing: 1 Superficial cultivation: 3.5 Spraying: 13.7 Mineral fertiliser: 2.2 (119 N) Organic fertiliser: 0.4 Mechanical weeding: 3		Ploughing: 1 Superficial cultivation: 3.5 Spraying: 12.6 Mineral fertiliser: 2.2 (119 N) Organic fertiliser: 0.4 Mechanical weeding: 4	

Source: ECOPHYTO R&D - Zone France

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

BEET

Principles of the 'integrated' level

The control techniques and avoidance strategies used are based on rationalising chemical interventions against diseases and animal pests. The use of observation and/or epidemiological modelling (via official recommendations) makes it possible to decide whether or not to treat in accordance with thresholds, maybe adapting the dose. For beet, the 'IPM' strategy, standing for Indice de Pression de Maladies which measures disease pressure, has been developed to help farmers conduct treatments based on damage thresholds. A weekly surveillance network of fields (RESOBET-FONGI) is managed by a collection of organisations during the summer to determine disease frequency and possible breaches of a treatment threshold, triggering advice on treatment.
More broadly, the introduction of this rationale benefits the agricultural advisory services of sugar refiners and can inform the messages and specific information notes issued by the ITB[a].
Preventive treatment of seeds can be used against yellow virosis, taking into account the strong probability of risk and the random nature of the efficacy of spray treatment for controlling this virus and its higher environmental impact.

Principles of the 'integrated at the CMP scale' level

This level relies in particular on :

- Choosing a variety which is more tolerant to leaf diseases (no other tolerance is currently known)
- Reducing the nitrogen dose in the search for a better Coefficient Apparent d'Utilisation (CAU, a measure of the efficiency of fertiliser use)
- Using stale seed beds when possible
- Avoiding all pre-emergence weeding
- Passing with a rotary hoe and then a mechanical hoe to limit post-emergence weeding.

Taken together, these practices reduce the recourse to herbicides compared to the previous level, and limit the use of fungicides by one treatment at full dose accompanied, in exceptional circumstances, by one remedial treatment.
The reduction in yield accompanying this strategy is estimated at 5-7 %. References from ITB[a] confirm that, provided a variety with a genetic profile tolerant enough to foliar diseases has been chosen, this strategy can provide an overall increase in yields for beet based on genetic progress and not linked to chemical inputs.

Principles of the 'integrated at the CS scale' level

For beet, this level uses mainly those levers for avoiding weeds beyond the possibilities presented earlier. A larger diversification in the rotation limits problems linked to the specialisation of spring dicotyledonous weeds. Reduced weed pressure provides the opportunity for effectively combining post-emergence chemical weeding localised in the row complemented by the use of mechanical weeding.
With no knowledge of experimental networks for beet grown in integrated systems, we have offered a characterisation of this level based on the expertise of the group and 'resource' people for this species. The strong hypotheses used share a great similarity in the crop characteristics between this level and the previous one. The yield losses are estimated to take into account the 'less than perfect' management of diseases.

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – beet

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	78.8	Identical to intensive	74	-5 to -7 %/level 1	72	- 7 to -10 %/level 1 (diseases)
TFI total	4.8	Expertise/ CA[a] advice	2.6		1.9	
TFI herbicides	2.3	1 pre-emergence weeding using a much reduced dose (mixture of products) + 3 post-emergence using a much reduced dose (mixture of products) + 1 post-emergence 2 years in 5 to 3 years in 4 using a much reduced dose (mixture of products)	0.8	Stale seed beds when possible Full weeding once or twice before second true leaf + early hoe and hoeing	0.5	Rotation (no specialisation of spring dicots) Stale seed beds when possible 1 full weeding or localised on the row + hoe and hoeing
TFI fungicides	1.6	1 systematic treatment + 1 treatment 3 years in 5	1.2	Choice of a variety tolerant to mildew, leaf spot and ramularia Limiting nitrogen 1 unique treatment at full dose + 1 possible remedial in problem years	0.8	Choice of a variety tolerant to mildew, leaf spot and ramularia Limiting nitrogen 1 unique treatment at full dose 2 years in 3 + 1 possible remedial in problem years
TFI insecticides	0.8	1 insecticide (beet fly) 2 years in 5 (2 treatments 1 year in 5)	0.5	Insecticide against beet fly but with increased intervention thresholds. Zero if seeds are treated	0.5	Insecticide against beet fly but with increased intervention thresholds. Zero if seeds are treated
TFI other	0.1	1 anti-slug 1 year in 10	0.1	1 anti-slug 1 year in 10	0.1	1 anti-slug 1 year in 10
No. passages	Ploughing: 1 Superficial cultivation: 3.1 Spraying: 7.5 Mineral fertiliser: 1.8 (110 N) Organic fertiliser: 0.5 Mechanical weeding: 0.8		Ploughing: 0.5 Superficial cultivation: 4 Spraying: 4.1 Mineral fertiliser: 1 (100 N) Organic fertiliser: 0.5 Mechanical weeding: 2	Stale seed beds Fertiliser localised on seeds + post-emergence 1 hoe + 1 hoeing	Ploughing: 0.5 Superficial cultivation: 4 Spraying: 3 Mineral fertiliser: 1 (100 N) Organic fertiliser: 0.5 Mechanical weeding: 2	Identical to CMP[g] scale with 20 N less Stale seed beds Fertiliser localised on seeds + post-emergence 1 hoe + 1 hoeing

Source: ECOPHYTO R&D - Zone France

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

PEA

Principles of the 'integrated' level

The rationale is based principally on the management of diseases and animal pests. Preventive fungicide treatments are used, triggered by taking into account an estimation of the infection potential of the field and weather forecasts (official recommendations). For the control of animal pests, these are triggered on reaching damage thresholds.

With no statistical data to help inform us on the performances of these strategies, we have characterised this level based on the advisors from France's Chambers of Agriculture, who in turn have been supported by experts in this crop from Unip-Arvalis, and enriched with local expertise on the frequency of occurrence of the principal pests. The yield is not affected by the technical strategy introduced at this level. The total estimated TFI[a] based on the data available is high (6.3), little different to the 'intensive' level, which clearly illustrates the fact that optimising the rationale for treatments does not reduce pesticide use in pea crops if it is not accompanied by the prophylactic measures relevant to the following levels.

Principles of the 'integrated at the CMP scale' level

There has been little work conducted on cropping pea in integrated systems. The weak availability of varietal choice (tolerance to diseases) limits the possibilities. The principles used at the crop management plan scale for cropping pea at this level therefore rest more on an increased rationalising of fungicide and insecticide interventions than real cultural control methods used in an avoidance strategy. This situation explains why there are relatively few differences between this level and the one which follows to the level described above.

Given this context, reducing the TFI in pea crops is difficult, but several paths do exist for reducing the use of insecticides:

- The replacement of spring peas with an alternative winter crop, sown late in autumn. Work in Picardy in 2005 and 2006 has shown there is a diminution of one passage of insecticides on average. In fact, the risk of injury from pea weevils and thrips in winter peas is much reduced, and aphids and midges arrive later in the cycle with reduced injury, especially from midges. However, winter pea crops often require an extra treatment with fungicides compared to spring peas.
- The homologation of an insecticide seed treatment (currently no product of this kind is authorised). Work conducted between 2002 and 2008 has shown a systematic reduction of one and sometimes two insecticide sprays, alongside greater efficacy against thrips, pea weevils and early aphids (viruliferous) which translates into improved yields.
- The practice of fumigation with phosphine once in the silo, which reduces bruchid populations. This treatment, which leaves no residue on the grains nor in the environment, is used in many countries but is very rare in France where numerous storage insecticides, which are easier to use, are authorised in cereals and where few silos are weatherproof (weatherproof silos are essential for this technique).

The latter two options are not specific to this level, but are 'possibles' which can potentially be used for all types of cropping systems.

Finally, there is margin for manoeuvre by adjusting the cropping in accordance with the markets. Currently some peas are produced for human consumption (export to the Indian sub-continent and industry for food processing) and some for seed, but the majority of the production is destined for animal feed (65 % of French production in 2008 and 85 % at the European level). And yet research for the 'human food' market leads to strategies which use a high level of insecticides to avoid downgrading of the crop (less than 2% of all peas to be perforated). The recent development of contracts for markets which are more lucrative makes it possible to grow peas at a low TFI insecticide. It is this logic that has been introduced in the propositions which follow. The thresholds for triggering treatment are, in this case, much higher than for food production and impasses can be tolerated more frequently.

For weeds, a stale seed bed is used whenever possible for dicotyledonous weeds. When the pressure from these weeds is limited, the use of a post-emergence mix of much reduced doses (chemicals of the Challenge type at 0.5 l plus bentazone at reduced dose) significantly reduce the TFI. The use of a spike harrow in peas also produces pretty good results.

For airborne diseases, several complementary tactics make it possible to reduce fungicide use to control anthracnose:

- Late sowing, recommended for winter peas (but not recommended for spring peas because of the sharp fall in yield potential)
- Fairly low sowing densities (there is often room for manoeuvre here)
- The use of tall varieties and resistance to lodging (an evolution is underway in varietal choice).

Looking forward, better forecasting of disease arrival (work is underway) could make it possible to avoid preventive treatments at the start of flowering. This development could impact all the alternative systems studied here.

The application of these principles leads to the hypothesis of a reduction in yields, estimated by experts, of around 5% compared to the 'intensive' level.

It should be noted that another promising development exists and that is the cropping of peas in association with cereals (a reflection of what is used in organic farming). This is certainly the development offering the greatest possibilities for the reduction of pesticides (herbicides and fungicides above all), on the condition that the mixtures used are of large sizes and resistant to lodging, such as triticale plus Assas. The major current brake on its adoption stems from the collection of crops on the farm: this 'new' crop, which must be sorted, is another crop to be managed at the same time as wheat, rape and spring peas. Work is underway within the ADAR 'pea-wheat associations' project which should in the short term provide the elements needed for growing this combination of crops.

Principles of the 'integrated at the CS scale' level

As for the previous level, there is little to help in the design of this level. At this level, the use of the 'rotation' lever makes it possible to opt for a weeding strategy that is a little different, combining post-emergence products and mechanical weeding as a complement. The lower infestation offered by a more diversified rotation makes this strategy sufficiently effective. The rest of the itinerary is the same as that proposed earlier.

ANNEX 2 : TYPICAL CROP MANAGEMENT PLANS FOR CROPS GROWN ACCORDING TO THREE DIFFERENT LOGICS

'INTEGRATED' LOGIC, 'INTEGRATED AT THE CMP SCALE' LOGIC AND 'INTEGRATED AT THE CS SCALE' LOGIC

Performance of different systems and justification for the practices introduced – pea

Performance indicator	Logic of the system					
	Integrated		Integrated at the CMP scale		Integrated at the CS scale	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	49	Identical to intensive	47		47	
TFI total	6.3	Epied 1998/2001 Optimisation for the essential on weeding and insecticide (rationalised)	3.75		3.5	Effect of the CS on infestation, cap on fungicide
TFI herbicides	1.5	1 base weeding (pre-emergence complete at 80 % dose) + 1 remedial anti-dicots and/or anti-gram. in 70 % of cases for 0.7 dose on average	1.25	Identical for level 1 for 50 % + all on post (anti-dicots and anti-gram. at low dose) on 50 %	1	Only post-emergence = base anti-dicots at half dose and anti-gram. at ½ dose for 50 % of surface. Complemented by mechanical weeding
TFI fungicides	1.8	2 treatments at reduced dose 3 years in 5 or 3 passages at 60 % dose	1	2 passages at ½ dose (choice of variety and lower density)	1	2 passages at ½ dose (choice of variety and lower density)
TFI insecticides	3	1 insecticide at emergence: pea weevils and/or thrips + 1 treatment for green aphids 1 year in 2 + 1 to 2 insecticides for bruchids (threshold for human food)	1.5	Pea weevils: ¼ year Thrips 1 year in 4: weak development of crop and strong pest presence. Treatment for bruchids at capped threshold of 400 (animal feed) 1 passage 3 years in 4. Sometimes green aphids	1.5	Pea weevils: ¼ year Thrips 1 year in 4: weak development of crop and strong pest presence. Treatment for bruchids at capped threshold of 400 (animal feed) 1 passage 3 years in 4. Sometimes green aphids
TFI other	0		0		0	
No. passages	Ploughing : 0.9 Superficial cultivation: 2.7 Spraying: 7.7 Mineral fertiliser: 0 Organic fertiliser: 0 Mechanical weeding: 0		Ploughing : 0.9 Superficial cultivation: 3.2 Spraying: 4.6 Mineral fertiliser: 0 Organic fertiliser: 0 Mechanical weeding: 0	Stale seed bed 1 year in 2	Ploughing: 0.9 Superficial cultivation: 3.7 Spraying: 4.3 Mineral fertiliser: 0 Organic fertiliser: 0 Mechanical weeding: 1.5	1 stale seed bed Harrow and/or hoe

Source: ECOPHYTO R&D - Zone France

OTHER SPECIES

➲ Triticale

Triticale is productive and less demanding than wheat. It is a minor crop in France (around 0.3 million hectares), and is principally grown for animal feed with only small markets for human food (bread and bakery products).
Its agronomic characteristics (hardiness, productivity and ability to smother weeds) make it an interesting crop when considering diversifying rotations. It merits its simplified characterisation here only at the 'integrated at the CS scale' level.
It shares, in part, the same pests as wheat, but is much more tolerant. Its aptitude for competition with weeds allows us to envisage skipping frequent weeding in this crop in situations where there is a diversified succession of crops.

➲ Sorghum

Principles of the 'integrated' level

Cropping of sorghum is not affected by serious insect or disease problems which need specific interventions using insecticides or fungicides. Its principal diseases are managed through genetics and the presence of toxic durrhine in the green parts of the plant could also explain the limited pressure exerted on sorghum by the various pests it shares with maize. Nevertheless, from time to time a localised application against click beetles (at sowing) or a treatment against early attacks from Mediterranean corn borers (after warnings) are recommended, but are rarely necessary and in reality are little used.
For weeding, the classic recommendation ('integrated' level) comprises two applications of herbicides:
• Against gramineae: either pre-emergence or early post-emergence (three leaf stage) for young gramineae; the humidity of the soil dictates the efficacy of these root-action products.
• Against dicotyledonous weeds and perennials post-emergence.
The ban on triazines has considerably limited chemical control for weeds in sorghum crops. The lack of herbicide solutions explains in large part the disaffection for this crop, which has grown increasingly unpopular over the past decade despite its clear advantages at the environmental level.
According to the floristic composition of the field, one or two applications are necessary. In cases of poor control, hoeing can be a remedial solution until the stage of seven to eight leaves.
In south-west France, sorghum can be planted in ploughed or unploughed clay-limestone soils, but in this case the winter vegetative cover should be destroyed. In loamy soils (boulbènes, a fine siliceous soil), ploughing is obligatory in spring.

Principles of the 'integrated at the CMP scale' level

Cropping of sorghum is, essentially, envisaged as a source of diversification in rotations. Its characterisation at this level is therefore not pertinent.

Principles of the 'integrated at the CS scale' level

Adaptations to the crop management plan can reduce the development of certain weeds, and therefore reduce the use of herbicides:
• By stimulating the competitive power of sorghum through closer spacing (down to 12.5cm), sufficient crop density and a variety which develops early.
• Delaying the sowing date (end of April until mid-May depending on the soil temperature) encourages more rapid crop development because of the thermophilic nature of sorghum. Delaying the sowing date also allows stale seed beds to be used to germinate non-dormant weed seeds at the surface and destroy plantlets before sowing of the crop. Adjusting the sowing density according to the earliness of the variety and the availability of water is essential for a successful crop. A crop which is over-populated has a strong negative impact on plants coming into ear and, as a consequence, the yield in dry conditions.

A solution for weeding can also be envisaged, following the same plan as for sunflower and maize. It necessitates, therefore, wider spacing during sowing, reducing the speed at which the crop canopy closes.
Through diversification of the rotation, we can avoid the accumulation of summer gramineae weeds (the most harmful). Furthermore, we can wait for higher infestations of summer gramineaes and perennials (bindweed) with a simplified workplan.

➲ Flax

The principles of growing flax at the 'integrated at the CS scale' level are based on:
- Choosing a variety which is tolerant to lodging (there is currently no other known tolerance)
- Moderated nitrogen fertilisation through the search for better use of nitrogen inputs
- Mechanical weeding as a complement (spiked harrow or hoe): with fewer weeds as a result of a more diversified rotation, the hypothesis is that we can cancel one herbicide in two for winter flax and reduce the single passage in spring flax.

The possibilities for avoiding diseases through changing sowing dates are not possible in flax because of the reduced optimal sowing periods. It should also be underlined that there is an absence of scientific work on attacks in this crop and possible avoidance strategies.
The introduction of this set of practices makes it possible to eliminate the use of a regulator and a share of the herbicides compared to current practice.
In itself, the alternative of spring flax to winter flax generates less pesticide use, but tends to have a slightly smaller production potential.

➲ Field (broad) beans

Principles of the 'integrated' level

Chemical weeding of field beans remains largely dominated by pre-emergence treatments (pendimethaline, imazamox, aclonifen and clomazone). The only post-emergence interventions constituting remedial solutions are limited to foliar treatments for gramineae.
Rapid and homogenous sowing of field beans makes it possible to limit the possibilities for weed development.
Stale seed beds in the autumn, after harvesting, are recommended in situations where no ploughing has taken place to ensure effective control of gramineae weeds and particularly foxtail.
As is the case for peas, field beans are affected by a number of pests.
The most common and serious **diseases** are anthracnose, botrytis and rust (the latter is the most dangerous for winter beans in the south of France). Varietal tolerances exist for anthracnose, as well as seed treatments. For the other two, only treatments for the vegetation are possible. The choice of product depends on the disease targeted, and certain products are effective against several different fungi. In the final analysis, one or two fungicide treatments are often necessary to control the principal fungal diseases.
There are three principal **animal pests** in field beans: pea weevils, bean aphids and bruchids. Pea weevils are more frequent in those areas where other leguminous crops are present (lucerne, peas etc.). However, the threshold for triggering treatment in field beans is higher than it is for peas (the presence of notches on all the leaves).
Bruchids do not have a direct consequence on yield. However, the presence of larvae in the beans, which finish their development during storage, strongly reduces quality, making the batch unsuitable for human food. Their control in the crop often requires several insecticide sprays. A DSS[a] (BruchiLis) has been recently developed by Arvalis-Unip to optimise interventions. Strips of plants in an advanced flowering stage to concentrate bruchid populations are currently being tested, as well as work on genetic resistance and semiochemicals. Finally, the use of fumigation in stored batches (obligatory for export) can reduce bruchid populations if it is used very soon after harvesting.

Principles of the 'integrated at the CS scale' level

Field beans are a source of diversification in rotations. In systems dominated by cereals they contribute to diversifying sowing dates, even for winter beans, which are generally sown later than wheat.

Compared to current practices, the reduction in pesticide use at this level is principally through :

• Weeding localised on the seed row (which requires specific equipment) as a complement to subsequent hoeing

• Raising the intervention threshold for insecticides against bruchids, which means accepting the risk of the batch being downgraded for animal feed (it is also requires the market to be well organised in two distinct channels).

Hemp

Hemp is a very good precedent crop because of its tap-root and ability to smother weeds ('clean' soil for the following crops). It can grow in all types of soil (loam, clay, sand and limestone) provided there are sufficient water reserves and that the soil has been correctly prepared (few clods and stones).

Parasitism and diseases are practically non-existent. Because of its rapid growth and vigour, hemp can overcome the majority of diseases and animal pests. Only one parasitic plant, Orobanche ramosa, threatens the crop, limiting the more extensive cultivation of hemp and provoking yield losses of up to 100 %, requiring a long rotation or even a total halt to hemp crops in infested fields. Defoliating moths (caterpillars), some leafminers, tipula, slugs, flea beetles, click-beetles as well as leafhoppers in south west France are present but injury is very limited in industrial crops.

The cropping of hemp is therefore highly simplified: no fungicide, insecticide and, theoretically, herbicide is necessary for an average yield of between 6 and 10 t/ha of straw depending on the year and the production area (and 1 t/ha of seed for threshed hemp).

Lucerne (alfalfa)

The major features of 'current' cropping are as follows :

• Weeding at the sowing stage (at low dose, at the cotyledon to two trifoliate leaves stage) complemented in the winter following the first cut to control new emerging weeds (low dose of total herbicide after drop in temperatures and the first frosts)

• No fungicides

• Occasional insecticide

• Ploughing after lucerne in cases of significant contamination in the current year by aerial pathogens present in residues or the soil surface, in particular various ascochytas and sclerotinia (dissemination of inoculum in neighbouring fields)

• In cases where parasitism is intense, respect for a minimum period of five years, maybe six to eight, between two lucerne crops in the same field, 10 years if the soil is infested with nematodes.

In systems seeking to reduce pesticide use, adaptations can be made to further reduce the already limited use in current systems. It is possible to stop the use of herbicides for control of gramineae, bringing forward the date of the first cut before seed formation in spring gramineae.

Performance of crops at the integrated level and justification for the practices introduced

Performance indicator	TRITICALE		SPRING FIELD (BROAD) BEANS		HEMP		SORGHUM		LUCERNE		FLAX (OILSEED)	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
Yield (q/ha)	62	-5 %/Common (bread) wheat	47	2008 national average (UNIP[a])	6 to 10 t	Reference: Burgundy, Franche-Comté, Eure. Good precedent to wheat	55		11 to 13 t		19	
TFI total	1.53		3.05	CS[a] effect on infestation, cap on fungicide	0		0.6		0.6/year		2.15	
TFI herbicides	0.9	More cover than wheat Anti-gramineae very rare Control of dicots through crop sequence Harrowing	0.8	Pre-emergence anti-dicots on half of fields (no post-emergence remedial treatment for dicots) + post-emergence remedial treatment for gramineae 1 year in 3 and only mechanical on the rest (hoe + harrowing)	0	Plant is very aggressive. Smothering effect (if sown in warmed soil)	0.6	Harrowing + post	0.9 over 3 years= 0.3	Chemical weeding at sowing. Nothing pre-emergence Basagran 0.4 l/h/dicots at sowing and Stratos frequency 1/3 /gramineae + remedial at ½ dose 1year in 3 for gramineae	0.9	1 chemical weeding + mechanical weeding
TFI fungicides	0.33	1 treatment at ½ dose 2 years in 3 (varietal choice)	0.75	1 passage ½ dose syst. + 1 earlier passage 1 year in 2 (treatment for rust on observation very rarely for anthracnose)	0	No diseases	0		0		0.75	1 autumn fungicide (eyespot) and ½ dose in spring (septoria)

Performance of crops at the integrated level and justification for the practices introduced

Performance indicator	TRITICALE		SPRING FIELD (BROAD) BEANS		HEMP		SORGHUM		LUCERNE		FLAX (OILSEED)	
	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value	Indicator value	Justification for the value
TFI insecticides	0.2	1 treatment 1 year in 5	1.5	Pea weevils, thrips: bottle-neck Bruchids with DSS[a] (climate) Bean aphids: when no regulation and breach of 20 % threshold for plants with 'sleeves' of aphids	0	No animal pests	0		0,3	Intervention if pea weevils (1 year in 3, but risk reduced with fall of peas)	0,5	1 treatment 1 year in 2
TFI other	0.1	No regulator (varieties with low susceptibility to lodging) Treatment of field edges if slugs	0		0		0					
No. passages	Ploughing: 0.5 Superficial cultivation: 3.3 Spraying: 1.7 Mineral fertiliser: 2 (125 N) Organic fertiliser: 0 Mechanical weeding: 1	Identical to common wheat 1 harrow	Ploughing: 0.9 Superficial cultivation: 3.7 Spraying: 3.7 Mineral fertiliser: 0 Organic fertiliser: 0 Mechanical weeding: 1.5	Harrow and/or hoeing	Ploughing: 1 Superficial cultivation: 1 Spraying: 0 Mineral fertiliser: 2 (90 N) Organic fertiliser: 0 Mechanical weeding: 0		Ploughing: 0.6 Superficial cultivation: 2.5 Spraying: 0.7 Mineral fertiliser: 0.9 (100 N) Organic fertiliser: 0 Mechanical weeding: 2		Ploughing: 0.5 Superficial cultivation: 2 Spraying: 0.5 Mineral fertiliser: 0 Organic fertiliser: 0 Mechanical weeding: 1 to 2 and 3 to 4 cuts	Spiked harrow on young lucerne	Ploughing: Superficial cultivation: 2 to 3 Spraying: 2 Mineral fertiliser: 2 (80 N) Organic fertiliser: 0 Mechanical weeding: 1	1 harrow

Source: ECOPHYTO R&D - Zone France

www.systemesdecultureinnovants.org

www.endure-network.eu

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