ENDURE

European Network for Durable Exploitation of crop protection strategies

Project number: 031499

Network of Excellence
Sixth Framework Programme

Thematic Priority 5
FOOD and Quality and Safety

Deliverable DR2.16

Report on RA2.6a – Designing Innovative crop protection strategies in arable rotations- Winter Crops Based Cropping Systems (WCCS):

Design of AS and IS1 cropping systems

Due date of deliverable: M35

Actual submission date: M42

Start date of the project: 1 January, 2007 **Duration**: 48 months

Organisation name of lead contractor: Aarhus University (AU)

Revision

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)	
Dissemination Level	
PU Public (Paper, Leaflets, Knowledge Compilation)	X
PP Restricted to other programme participants (including the Commission Services) (Final Report)	
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

Table of contents

Glossary

Definitions in the context of this report

Pests
Herbivorous arthropods, fungal diseases and weeds that have the potential to cause economically significant damage to the maize crop.

Pesticides
Chemical and non chemical plant protection products applied in the form of soil granules, on-plant microgranules, seed treatments or spray formulations in maize growing against arthropod pest nsecticides, acaricides), fungal diseases (fungicides), and weeds (herbicides).

Alternative pest control methods
Pest control methods not relying on chemical pesticides.

Integrated pest management (IPM)
Concept of using different techniques in combination to control pests efficiently, with least adverse effects on the environment and most specificity to the particular pest. A set of decision rules is used to identify the need for and selection of appropriate control actions that provide economic benefits to growers and society while keeping chemical control of pests to a minimum.

Treatment Frequency Index (TFI)
An index of the intensity of pesticide use, calculated as the total number of full doses of a pesticide applied to a given crop in a given amount of time (usually a growing season). The index can also be calculated as the average annual TFI for a rotation.

Summary

Winter crops constitute the principal component of most crop rotations in arable cropping in Northern Europe. Winter wheat, winter barley and winter oil seed rape are the primary crops grown among the winter crops. These crops are preferred because of a higher yield potential than similar spring grown crops and a good adaption of winter crops to the climate and soils prevailing in Northern Europe. While the profitability of growing these crops is larger compared with spring sown crops, the input from pesticides needed is higher, adversely affecting the environment. Previous case studies in ENDURE have predominately been looking at tactics and strategies for pesticide reductions in single crops only. This case study is taking advantage of the knowledge amalgamated in previous ENDURE activities and brings it into a cropping system context. The aim is to change and redesign current winter crops based cropping systems in order to reduce the necessity of pesticides. The whole activity is exploring practical scenarios for reducing pesticides taking into account local/country-related priorities. The case study includes redesigned cropping systems for the UK, Denmark and middle and northern areas of France while more basic information is presented for Germany also. Current winter crops based cropping systems in the three countries have rather large differences in terms of pesticide use with France and the UK having treatment frequent indexes (TFI) 3-4 times higher than in Denmark. However, the case study has revealed considerable scope for reductions in pesticide use by employing agronomic methods and technologies that are already available to farmers, or are close to being so, but this scope varies greatly between countries depending upon how much pesticide usage has already been reduced and upon the local socio-economic and pedo-climatic context. The approach suggested by the UK and Denmark relies on a mix of preventative and curative pest management actions such as modifying the existing systems, reducing pesticide use through the introduction of both low-tech practices (e.g. optimized/adjusted dosages, sowing densities and dates, cultivars, crop sequences, tillage etc.) and hi-tech practices (e.g. GPS-guided applications, pesticide targeting, decision support systems). France, however, emphasizes preventative measures, re-designing the whole cropping system to limit the risk of pest attacks, meaning that innovations developed from a cropping system with no pesticide (e.g. organic CS) relying on all possible low technology means to control pests, pesticides only being added when alternative practices fail. The estimated maximum TFI reductions achieved by the most far-reaching proposals for redesigned systems in Denmark, France and the UK were 37%, 94% and 56%, respectively.

Teams involved

	Institute	Country
ACTA	Association de coordination technique agricole	France
INRA	L'Institute National de la Recherche Agronomique	France
RRES	Rothamsted Research	UK
AGROS	Agroscope Research Station ART	Switzerland
AU	University of Aarhus	Denmark
DAAS	Danish Agricultural Advisory Service	Denmark
JKI	Julius Kühn-Institut (former BBA)	Germany

The RA2.6a case study has been running for 13 months in which 3 meetings have been held.

Geographical areas covered

Totally 3 countries and 5 regions are included in this study:

- The UK: arable area of England
- Denmark: whole country
- France: three regions: Bassin Parisien, Poitou Charentes, Bourgogne

Degree of validation and operability of findings

Data, information and experts' knowledge and experience were gathered and discussed over 3 workshops. Subsequently, all the information collected has been formulated into cropping systems designed for a reduced reliance on pesticides. The work has been discussed in collaboration with invited extention services with great knowledge about cropping in practice. The report is approved by all involved teams. It has also been sent to Endure on M39 for approval.

The AS systems are all designed to be ready for implementation in practice or to serve as a source for inspiration of similar cropping systems aiming at reducing pesticide input. The IS1 systems also contain information of practical value but its functionality and applicability in practical cropping has some uncertainties owing to the suggestion of still immature technologies.

The work on developing AS and IS1 systems are planned to evolve into a scientific paper or conference paper depending on the support from economic analyses on the feasibility of the proposals. Leaflets containing the major elements of the AS systems are planned for DK, the UK, FR, audience: extension services. The work is also going to be presented at national and international conferences.

Introduction

The case study on Arable Crop System studies (RA2.6) was initiated in January 2008. This case study was formulated as a consequence of previous case studies predominately looking at single crops only. There was a need to take advantage of the knowledge amalgamated in other ENDURE activities and bring it into a cropping system context. The question arose whether current cropping systems could be changed or redesigned to reduce the necessity of pesticides. Thus not only the crop protection actions taken in the single crop but also the whole cropping systems as such should be scrutinized to identify where and when relevant savings in pesticide input could be achieved. The whole activity is exploring practical scenarios for reducing pesticides taking into account local/country related priorities.

The two first meetings in RA2.6 were used to identify the cropping systems of relevance for European arable cropping. The expertise and data available within the frame of ENDURE, and how this might contribute to the RA2.6 case study, were analyzed and discussed. These meetings resulted in three sub-activities as relevant forums for the continuation of RA2.6, because important European crop rotations, mainly composing of cereals, were seen to differ considerably between Northern Europe and Central/Southern Europe. Cropping systems having a high proportion of winter crops, notably winter wheat, winter barley, and winter oil seed rape, are typical for Northern Europe. It was decided to deal with such cropping systems in sub-activity RA2.6a.

RA2.6a began in mid-July 2008 and a core group consisting of INRA, RRES, JKI and AU was established. Each core group member represented the country and regions within the country in which winter crops based cropping systems (WCCS) would have particular relevance: Middle and Northern France, the UK, Middle and Northern Germany and Denmark. In addition, other institutions working with extension services, having close contacts to the producers, have supported the work in RA2.6a, notably DAAS (Denmark), ACTA, CETIOM (France) and two UK extension services participating in one of the planning meetings (Velcourt, subcontracted to ENDURE SA4.5 and TAG [The Arable Group] on an *ad hoc* basis).

The work in RA2.6a has been divided into two overall sections of which this report is dealing with the first section. In the first section, the work has focussed on the design of alternative system WCCS (AS) and level 1 innovative system WCCS (IS1). AS are defined as systems that include current information from organic and integrated pest management systems. Several measures and methods, such as tillage practices, rotational effects, crop residue management, mechanical weeding, crop variety features, reduced pesticide doses, etc. have been reviewed, both solely and in combinations. Therefore, the AS proposed are based on a solid foundation. IS1 are also based on existing knowledge and technologies but information about their functionality and likely positive effects in terms of reducing pesticide input, when included in a cropping system context, is lacking or very slight.

Expertise internal and external to ENDURE was identified for listing main pest problems according to their importance in current crop protection systems in WCCS. These major pests are presented in Appendix B, and AS and IS1 are mainly addressing these problems. RA2.6a has also gathered information about the effects of agronomic methods on pests, presented in Appendix C.

Existing knowledge of applicable methods to include in crop protection strategies for WCCR were reviewed in the first section of RA2.6a with a special focus on preventive, cultural and non-chemical methods, reduced pesticide doses, variety features, etc. The review and discussions have resulted in the formulation of AS and IS1 systems, which are presented in details in Appendix A. A first attempt to assess the systems according to applicability, economy, environmental impact, landscape perception, social impact, etc. was carried out with the help from the DEXiPM assessment tool from RA2.4/3.1 and that is currently under development. The systems were also assessed according to estimates of the reductions in pesticide usage that they achieved. Pesticide usage was estimated as the average annual Treatment Frequency Index (TFI) over the rotation.

This report summarizes the work done to design the AS and IS1 systems for WCCS in Denmark, France and the UK.

State of the art

Overwintering crops constitute the principal component of most crop rotations in arable cropping in Northern Europe. Winter wheat, winter barley and winter oil seed rape are the primary crops grown among the winter crops. Pig producers and stockless arable growers have a high proportion of over-wintering crops, especially winter wheat, in their crop compositions. Dairy farmers and beef producers have other needs where fodder crops, such as silage maize and pastures for grazing and silage, are prioritized. This picture of crop growing is common for most North European countries. However, the extension of winter crops declines rapidly when reaching the Northern parts of Scandinavia where the climate becomes harsher and outwintering becomes more likely.

Winter crops are preferred because of a higher yield potential than similar spring-grown crops and a good adaption of winter crops to the climate and soils prevailing in those parts of Europe. Profitability of growing these crops is simply larger and the input from pesticides needed is higher compared with spring-sown crops. The dominance of winter crops is reflected in the national cropping areas covered by winter crops (winter wheat, winter barley and winter oilseed rape). In Denmark, winter crops covered 35% of the total area farmed in 2008 and winter wheat was the largest cereal crop covering 42% of the total area with small grain cereals (source: The Danish Advisory Centre 2008). In France, winter crops cover 65% of the total area under arable crop farming in 2007, and winter wheat was also the largest winter crop covering 56% of the area cultivated with winter crops (Source: AGRESTE, http://agreste.agriculture.gouv.fr). In the UK, winter crops covered 69% of the total arable area cropped with winter wheat accounting for 64% of the total area cropped under small grain cereals (Source: Defra Agricultural and Horticultural Survey, 2007).

In the UK, Denmark and northern parts of France, overwintering crops often compose 100% of the crop rotation whereas spring-sown break crops mostly are grown in less than 25% of a crop sequence. (The section *Analyses on typical crop rotation compositions in France, the UK and Denmark* below deals more thoroughly with crop rotations typically found in the North European countries). Such strenuous crop rotations or crop sequences easily favour specific pest problems of which the most important ones are summarized in Appendix B. Some of these pest problems might become very severe, usually requiring an extensive use of pesticides. For example the enrichment of annual grass weeds, notably *Alopecurus myosuroides, Bromus spp.* and *Apera spica-venti*, following intensive cropping of winter wheat, put a strong pressure on herbicide use (Melander *et al.*, 2008). These annual grasses cause high yield losses and there is a strong economic incentive to control them effectively (Melander, 1995). In practice, this means full doses and sometimes several applications per season. Effective grass weed control normally gives a return to the grower but increasing pesticide consumption evidently goes along with a high demand for grass weed control. This has particularly been the case in Denmark in recent years where reduced tillage systems have further accentuated the problems (Melander *et al.*, 2008; Clarke *et al.* 2000; Orson 2006). In addition to herbicides, fungicide use have also been seen to increase when the crop sequence have more winter wheat and becomes less varied (Jørgensen & Kudsk, 2006). Pesticide consumption in the different crops and countries are further discussed in the section below "Treatment Frequency Indices for each country".

Current winter crops based cropping systems (WCCS) with a high proportion of winter cereals are pesticide demanding and match poorly with the current political goals of many European countries to reduce pesticide input. For example countries such as Denmark, Germany, France, the Netherlands and Sweden have already launched pesticide action plans to move agriculture away from a high dependence on pesticides to a lower dependence. Ideally, crop sequences should have a much stronger mixture of annual crops with varied sowing times (spring versus autumn) and periods with perennial crops to really counteract unwanted and severe pest problems, thereby limiting the need for pesticides. However, this is not very likely to happen because crop choice and the configuration of cropping systems is mainly driven by the demand for cereal staples and by short-term economic factors such as the prevailing commodity prices and the yield potential of the crops. A widespread cropping of WCCS will still prevail in North European agriculture in the near future, and crop protection systems will need to deal with that scenario. In the short term, only modest changes of the crop sequences appear feasible and less dependence on pesticides should mostly rely on other measures, such as preventive, cultural and non-chemical control methods along with improved spraying technologies and optimized pesticide doses. In the main, this is the situation addressed by the AS and IS1 systems proposed in this report. However, in the longer term new innovations within breeding, electronics, robotics, models for forecasting pest incidences and many other techniques may change the situation entirely. The second part of the RA2.6a case study will go further into such future scenarios of WCCS.

Interactions with other ENDURE activities

The case study has benefitted strongly from interacting with the work on developing the assessement tool DEXiPM. DEXiPM is an outcome of the interactions between other ENDURE activities, notably RA2.4 / RA2.3 / RA3.1 / RA3.2 / RA3.4 / RA3.5, covering various issues such as environment, economy, socio-economy and landscape management. The DEXiPM tool is presented in more details in the section: 'DEXiPM and links to RA2.6a' on page 25 in this report.

The outcomes of the previous RA1 cases studies on *Winter wheat* and *Integrated weed management* have delivered valuable information on relevant pests to consider for WCCS including prospects of combining preventive, cultural and direct control tactics. EUROWHEAT in IA2.1 has provided a list of cultural tactics and its potential for suppressing pests in WCCS. RA2.6a has further extended the list. RA4.2 has informed about the potential of genetics to redesign cropping systems and RA2.2 is covering important information about more advanced technologies of relevance to IS1 and IS2.

Assessments of the potential for biological control agents to reduce TFI in AS and IS1 systems and of the influence of landscape and habitat management on pest populations have benefitted from interaction with RA4.3 and RA2.3.

Analyses on typical crop rotation compositions in France, the UK and Denmark

Denmark

In order to investigate the composition of the Danish crop rotations, the information in the Danish Field Database (DFD) is used.

Description of the Danish Field Database (DFD)
DFD is a database compiling information on crop and working processes on field level. The information is the same as the farmers give to the authorities to get their EU subsidies. Currently more than 1.45 million hectares (approx. 57%) of the Danish arable land is stored in the DFD. As the database holds information several years back, it therefore gives a unique opportunity to investigate, on field level, the cropping history in Denmark.

Method and results
DFD contains information at field level, as far back as the farmer/advisor has registered his field data. The further back in time, the fewer fields will be available, as some farmers only recently joined the database. Initially the data in the database were therefore examined under the following assumptions:

- Only fields with a 4-year known cropping sequence were included (approx. 110,000 fields), despite the fact that in many cases it is advised to have more than 4 years between similar crops (e.g. oilseed rape and potatoes)
- The crop rotation must be independent of year, meaning that only the sequence of crops matters (e.g. crop rotation A B C D will be similar to C D A B but not C A D B)
    - In order to secure this, the computer runs through each individual crop rotation and compares it with all the remaining rotations, by shifting the year 4 times.

Performing the mentioned routine in DFD reveals 28,976 crop rotation combinations of which only 9618 crop rotations occurs more than one time and only 10 occurs in more than 1% of the incidences. As can be seen from Table 1, the most common crop rotation is winter wheat grown in monoculture. It must however be noted, that no single crop rotation occurs in more than 3.6% of the cases.

Table 1. Top ten 4-year crop rotations in Denmark. WW: Winter wheat, WB: Winter barley, WR: Winter oilseed rape, M: Maize (silage), GL: Grass ley, SB: Spring barley, F: Fallow, O: oats.

Crop rotation	Year 1	Year 2	Year 3	Year 4	Total	% af fields
1	WW	WW	WW	WW	3963	3.6
2	WB	WR	WW	WW	3093	2.8
3	WW	WW	WW	WR	2213	2.0
4	M	M	M	M	1794	1.6
5	GL	GL	GL	GL	1619	1.5
6	SB	SB	SB	SB	1548	1.4
7	F	F	F	F	1161	1.1
8	WB	WR	WW	SB	1093	1.0
9	WW	WW	WW	SB	1088	1.0
10	O	WW	WW	WW	920	0.8

The above mentioned is relatively clearly described, mainly due to the large number of fields. In order to catch possible longer crop rotations, the next step was to perform the same analysis 6 years back. By doing so, the amount of fields was reduced to approx. 22,000. In Table 2 it is seen that the most common crop rotation again is winter wheat in monoculture, (2.65% of the cases).

Table 2. Top ten 6-year crop rotations in Denmark. WW: Winter wheat, WB: Winter barley, WR: Winter oilseed rape, M: Maize (silage), GL: Grass lay, SB: Spring barley, F: Fallow, GK: Grass clover, CT: Christmas trees.

Crop rotation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total	% af fields
1	WW	WW	WW	WW	WW	WW	599	2.65
2	M	M	M	M	M	M	309	1.37
3	WW	WW	WW	WW	WW	WR	260	1.15
4	WB	WR	WW	WW	WW	WW	237	1.05
5	F	F	F	F	F	F	169	0.75
6	GL	GL	GL	GL	GL	GL	152	0.67
7	F	F	F	F	F	GK	145	0.64
8	WW	WW	WW	WW	WW	SB	131	0.58
9	SB	SB	SB	SB	SB	SB	118	0.52
10	CT	CT	CT	CT	CT	CT	96	0.42

One could easily conclude, based on the above analysis, that wheat after wheat is the most common crop rotation in DK. The conclusion is, however, rather that the vast majority of the farmers actually use very different crop rotations, as more than 85% of the crop rotations fall outside "top 10" in Tables 1 and 2.

In order to get a little closer to the answer, another analysis was performed on the 5-year rotations (approx. 50.000 fields). In this analysis, the crops were divided in 4 groups, defined as:

- Winter cereals (wheat, barley, triticale and rye)
- Winter oilseed rape
- Spring cereals (wheat, barley and oats)
- Other

The 5-year rotations were then compiled in the different groups according to the occurrence of the different crops (e.g. the rotation 60-20-20-0 consists of 60% winter cereals, 20% winter oilseed rape and spring cereals and nothing else). The results of this analysis can be seen in Table 3.

By compiling the rotations in this way a much better indication of the status of the Danish crop rotations can be obtained. It is e.g. seen from Table 3 that more than 10% of the crop rotations in Denmark consist of winter cereals, only separated by 1 year of oilseed rape. In terms of weed control, and especially grass weeds, this is not a durable way. The reason for these results should be found in the large production of pigs. Farmers with pigs can earn significantly more from growing only winter cereals, despite the increased costs of pesticides (approx. 100-150 €). This is because the feeding value from e.g. winter wheat is higher than the alternative spring crops. Furthermore, if oilseed rape is used, the farmer has to buy in extra wheat for fodder, at a price that often is €2 higher/100 kg than what he can sell his own produce for. It should, however, also be mentioned that the advantage of growing winter crops in monoculture is easily compensated by the severity of resistance problems, etc. which most likely will occur in such a crop rotation over time.

Table 3. Results of the analysis of 5-year rotations, followed by a compilation of the results in groups. The total area analyzed is 232,321 hectares. W: Winter cereals, WR: Winter oilseed rape, S: Spring cereals, O: Other crops.

	% in crop rotation					
Rotation no.	W	WR	S	O	Area (ha)	% of analyzed area
1	0	0	0	100	35,108	15.1
2	80	20	0	0	25,770	11.1
3	60	20	20	0	16,461	7.1
4	0	0	20	80	16,440	7.1
5	100	0	0	0	15,862	6.8
6	0	0	40	60	9,788	4.2
7	80	0	20	0	8,580	3.7
8	40	20	40	0	7,737	3.3
9	20	0	20	60	6,816	2.9
10	60	0	40	0	6,400	2.8
11	40	20	20	20	6,184	2.7
12	40	0	40	20	6,065	2.6
13	60	0	20	20	5,885	2.5

% in crop rotation						
Rotation no.	W	WR	S	O	Area (ha)	% of analyzed area
14	40	0	20	40	5,363	2.3
15	0	0	60	40	5,139	2.2
16	20	0	40	40	5,047	2.2
17	40	0	60	0	4,815	2.1
18	0	0	100	0	4,724	2.0
19	20	0	0	80	4,139	1.8
20	60	20	0	20	3,870	1.7
21	20	0	80	0	3,489	1.5
22	20	0	60	20	3,396	1.5
23	60	0	0	40	2,946	1.3
24	0	0	80	20	2,940	1.3
25	40	0	0	60	2,878	1.2
26	80	0	0	20	2,627	1.1
27	20	20	60	0	2,551	1.1
28	60	40	0	0	2,424	1.0
29	40	20	0	40	1,895	0.8
30	20	20	40	20	1,769	0.8
31	20	20	20	40	1,410	0.6
32	40	40	20	0	1,159	0.5
33	20	20	0	60	560	0.2
34	0	20	20	60	402	0.2
35	0	20	80	0	392	0.2
36	0	20	40	40	392	0.2
37	0	20	60	20	319	0.1
38	0	20	0	80	202	0.1
39	40	40	0	20	120	0.1
40	20	40	20	20	88	0.0
41	20	40	0	40	83	0.0
42	20	40	40	0	49	0.0
43	0	40	20	40	20	0.0
44	40	60	0	0	17	0.0
45	0	40	40	20	1	0.0
46	0	60	0	40	0	0.0

From the results it is also seen that the third most common rotation is one of those recommended by the advisors in practice, in which two years of winter wheat are separated by one year of spring cereals and one year of winter oilseed rape. Even though it will be better with 2 years of spring cereals, this rotation is much better than number 2, in terms of reducing weed problems. In Table 4, the same analysis is performed for the 4-year rotations. In this case, there are a lot more fields in the analysis (covering 548,112 hectares), increasing the confidence in the data. The results indicate that continuous growing of winter cereals with one year of oilseed rape again is the second most important rotation in the 4-year analysis.

Table 4. Results of the analysis of 4-year rotations, followed by a compilation of the results in groups. The total area analyzed is 548,112 hectares. W: Winter cereals, WR: Winter oilseed rape, S: Spring cereals, O: Other crops.

	% in crop rotation					
Rotation no.	W	WR	S	O	Area (ha)	% of analyzed area
1	0	0	0	100	92,744	16.9
2	75	25	0	0	76,846	14.0
3	100	0	0	0	51,327	9.4
4	0	0	25	75	41,645	7.6
5	50	25	25	0	35,656	6.5
6	75	0	25	0	31,347	5.7
7	0	0	50	50	24,396	4.5
8	50	0	50	0	22,500	4.1
9	50	0	25	25	21,240	3.9
10	25	0	25	50	19,816	3.6
11	25	0	50	25	16,013	2.9
12	0	0	100	0	15,569	2.8
13	25	0	75	0	14,386	2.6
14	25	0	0	75	13,718	2.5
15	0	0	75	25	13,636	2.5
16	25	25	50	0	10,592	1.9
17	50	0	0	50	10,061	1.8
18	75	0	0	25	9,928	1.8
19	50	25	0	25	9,351	1.7
20	25	25	25	25	8,017	1.5
21	25	25	0	50	2,790	0.5
22	50	50	0	0	1,607	0.3
23	0	25	75	0	1,599	0.3
24	0	25	25	50	1,240	0.2
25	0	25	50	25	1,094	0.2
26	0	25	0	75	450	0.1
27	25	50	25	0	414	0.1
28	25	50	0	25	64	0.0
29	0	50	25	25	49	0.0
30	0	50	0	50	10	0.0
31	0	50	50	0	6	0.0

UK

Survey data

In order to investigate the composition of the UK crop rotations, information was sought from the UK Defra-funded winter wheat and winter oilseed rape pest and disease surveys. The winter wheat surveys started in 1975 and have been conducted annually with the exception of 1984 and 1985. At least 300 crops are assessed each year in a random sample taken from farms across England and Wales (1975-2002) and then England only from 2003 onwards. The winter oilseed rape survey began in 1987 and involves assessment of 100 crops on three occasions during the growing season. The survey included crops in Wales until 2002 and then England only from 2003 onwards. CropMonitor (www.cropmonitor.co.uk) took over the surveys in 2003.

Analysis of data indicated that the was no "typical rotation" for the UK but many different combinations of crop sequences depending on many different factors including market forces. A number of different analyses were done to build up a framework for the most usual crop sequence for an arable setting based on a winter crop-based rotational context.

Both sets of survey data record the following categories of crops:
Winter wheat, other cereals, pulses/legumes, potatoes, grass, fallow, other crops, oilseed rape, Setaside. No distinction is made between spring or winter crops for 'other cereals' or oilseed rape.

Proportion of each crop that was preceded by another arable crop

The survey data were analyzed to indicate which proportions of the crop was preceded by each of the following arable crops: winter wheat, winter barley, winter oilseed rape, spring barley, potatoes, winter beans, spring beans, sugar beet, other.

Table 5a. Winter Wheat - Per cent of crops (where previous crop known) preceded by different crops for England and Wales (Welsh data included only up to 2003).

Previous crop		Harvest years						
		2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Winter wheat		23.81	33.96	27.53	23.90	27.80	28.27	25.95
Other cereals		7.14	5.28	5.57	5.51	5.41	3.89	4.15
Pulses/legumes		19.05	12.83	13.94	14.34	15.83	13.43	9.00
Potatoes		5.95	10.57	4.88	6.25	5.41	3.53	7.61
Grass		2.08	3.77	2.44	2.21	3.09	2.47	6.57
Fallow		0.3	0.38	0.35	0	0.77	0.35	1.04
Other crops		9.52	9.06	14.63	16.18	12.36	11.31	13.15
Oilseed Rape		22.32	17.74	23.0	28.31	25.48	32.86	29.76
Setaside		9.82	6.42	7.67	3.31	3.86	3.89	2.77

Table 5b. Winter Barley - Per cent of crops (where previous crop known) preceded by different crops for England and Wales (Welsh data included only up to 2003).

Previous crop		**Harvest years**			
		2002	**2003**	**2004**	**2005**
Winter barley		19.32	18.95	19.67	21.23
Other cereals		74.92	68.95	67.76	73.18
Pulses/legumes		0.34	0.53	2.73	1.12
Potatoes		1.69	3.68	0	0.56
Grass		1.02	3.16	1.09	0.56
Fallow		0	0	0	0
Other crops		0.68	1.58	3.83	1.68
Oilseed Rape		0.34	1.05	1.64	1.12
Setaside		1.69	2.11	3.83	0.56

Table 5c. Winter Oilseed Rape - Per cent of crops (where previous crop known) preceded by different crops for England and Wales (Welsh data included only up to 2003).

Previous crop		Harvest years						
		2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Winter wheat		47.31	69.89	61.22	61.22	52.08	53.0	64.65
Other cereals		39.78	25.81	35.71	32.65	42.71	40.0	31.31
Pulses/legumes		2.15	1.08	0	1.02	0	1.0	0
Potatoes		0	0	0	0	0	0	1.01
Grass		0	0	0	0	0	1.0	0
Fallow		0	0	0	0	1.04	0	0
Other crops		0	0	0	1.02	0	0	1.01
Oilseed Rape		0	1.08	0	1.02	0	1.0	0
Setaside		10.75	2.15	3.06	3.06	4.17	4.0	2.02

Where winter wheat was being grown, the two main preceding crops were winter wheat (presumably a "first" wheat) or a break crop (Table 5a). It is interesting to note that ~50 % of previous break crops were oilseed rape and/or pulses/legumes in the years 2002-2006 but that more recently pulses/legumes seem to be grown less with oilseed rape gaining in dominance as the break crop of choice, presumably since winter oilseed rape became a more profitable option. Winter oilseed rape is also attractive to some growers as it provides a window of opportunity for grass weed management whilst also returning a profitable crop, whereas pulses and legumes are currently less profitable. Table 5b again indicates the dominance of winter wheat in the rotation accounting for the high percentage of "other cereals". This also indicates the role that winter barley has as the non-wheat cereal break crop presumably again because it is still relatively profitable in comparison to other "non-wheat" options. It should be noted that winter barley tends to be grown on a "regional" basis, predominantly in the more northern regions of the survey data area. Table 5c higlights the dominance of winter wheat within the arable rotation. These three tables support the notion that the most common crop sequence tends to include 1-3 years of winter wheat, possibly followed by barley, followed by a break crop which was predominantly winter oilseed rape.

Common crop sequences

The survey data were analyzed to identify the five most common crop sequences that followed winter wheat, winter barely or winter oilseed rape and to indicate the proportion of each crop that was followed by each sequence.

Key to crop sequences:
W = winter wheat (not coded for in winter barley survey - in other cereals category)
B = winter barley (coded for in winter barley survey - otherwise in other cereals category)
C = other cereals
P = pulses/legumes
S = potatoes
G = grass
O = other crops
R = oilseed rape
A = setaside

Table 6a. Crop sequences most commonly following winter wheat (and the percentage of winter wheat crops followed).

Harvest year	Rank	Crop sequence 1	2	3	4	5			
2002		R,C,W,W	W,W,W,W	W,R,W,W	P,W,W,R	P,W,R,W			
	%	4.11	3.77	3.77	3.42	3.42			
2003		W,W,W,W	W,P,W,W	W,R,W,W,	W,R,C,W	R,C,W,W			
	%	4.26	3.40	3.40	2.98	2.98			
2004		W,W,W,W	R,C,W,W	W,R,W,W	R,W,P,W	W,R,C,W			
	%	5.04	4.65	3.49	3.10	2.71			
2005		R,W,P,W	R,C,W,W	W,W,W,W	R,W,W,R	P,W,W,R	R,C,W,R		
	%	4.58	4.17	3.33	3.33	2.92	2.92		
2006		R,C,W,W	W,W,W,W	R,W,P,W	R,C,W,R	W,R,W,W			
	%	6.40	4.40	4.40	4.40	3.80			
2007		W,R,C,W	P,W,R,W	W,R,W,W	W,W,W,W	R,W,W,R	R,W,P,W	R,W,R,W	R,C,W,R
	%	4.47	4.07	3.66	3.25	3.25	3.25	3.25	3.25
2008		W,R,W,W	G,G,G,G	R,W,R,W	W,W,W,W	O,W,R,W	R,W,W,R		
	%	5.41	4.63	4.25	3.09	2.70	2.70		

Table 6b. Crop sequences most commonly following winter barley (and the percentage of winter barley crops followed).

Harvest year	Rank	Crop sequence 1	2	3	4	5	
2002		C,C,R,B	C,R,B,C	C,C,P,C	C,C,R,C	C,O,B,C	
	%	8.18	5.91	3.18	3.18	3.18	
2003		C,C,R,B	C,R,B,C	C,C,R,C	C,P,C,R	C,C,C,R	
	%	5.63	5.0	4.38	4.38	3.75	
2004		C,O,B,C	B,B,B,B	C,C,R,B	C,C,C,C	C,C,P,C	C,C,R,C
	%	5.84	5.19	5.19	3.9	3.25	3.25
2005		C,C,R,B	B,B,B,B	C,G,G,G	C,C,O,B	C,O,B,B	C,R,C,P
	%	8.72	5.37	5.37	2.68	2.68	2.68

Table 6c. Crop sequences most commonly following winter oilseed rape (and the percentage of winter oilseed rape crops followed).

Harvest year	Rank	Crop sequence 1	2	3	4	5		
2002		W,W,R,W	C,W,W,R	C,W,P,W	C,W,O,W	W,W,P,W	W,R,W,W	W,R,W,R
	%	15.66	9.64	6.02	4.82	3.61	3.61	3.61
2003		W,W,R,W	W,W,P,W	C,W,W,R	W,C,W,R	W,P,W,R	W,R,W,R	C,W,A,W
	%	12.64	8.05	6.90	4.60	4.60	3.45	3.45
2004		W,W,R,W	W,W,P,W	W,W,O,W	C,W,W,R	W,P,W,R	C,W,C,W	C,W,S,W
	%	12.50	5.68	5.68	4.55	3.41	3.41	3.41
2005		W,W,R,W	C,W,W,R	W,W,P,W	W,P,W,R	W,W,R,C	C,W,W,P	
	%	10.59	5.88	4.71	4.71	3.53	3.53	
2006		C,W,R,C	C,W,W,R	W,W,R,W	W,P,W,R	W,P,W,W	W,R,W,W	C,W,W,P
	%	6.59	6.59	5.49	5.49	3.30	3.30	3.30
2007		C,W,R,C	W,P,W,R	C,W,W,R	C,W,P,W	W,O,W,R		
	%	7.14	6.12	6.12	5.10	4.08		
2008		W,W,R,W	W,R,W,R	W,W,P,W	C,W,R,W	W,P,W,R	C,W,R,C	W,R,W,W
	%	11.34	6.19	5.15	5.15	4.12	4.12	4.12

As with previous data presented for the UK (Tables 5a-c), Tables 6a-c indicate a diverse series of cropping sequences dominated by winter wheat as the main crop and winter oilseed rape as the primary break crop. However, there was no particular temporal pattern, with the ranking of sequences changing from year to year, presumably determined by market forces within the industry. Table 6a indicates this very well with various sequences involving at least 2 winter wheats in the previous 4 seasons for all crop sequences for all years. The exception to this was 2008 when 4.63% of crops that were sown to winter wheat crops were sown on land that previously had been long-term (4 years at least) grass leys, presumably because winter wheat was so profitable that growers required more land to sow into wheat. In all years surveyed, a small proportion of growers grew what could be considered “continuous wheat” with the percentage of crop sown to W-W-W-W-W ranging from 3.09% (2008) to 5.04% (2004, when this crop sequence was the largest percentage of any crop sequence that year). Table 6a also highlights the shift away from pulses and legumes towards winter oilseed rape as the break crop of choice in recent years.

There were fewer data concerning crop sequences followng winter barley but they further demonstrated the dominance of cereals in the rotation. Winter barley rarely occurred more than one year in three except in 2004 and 2005 when continuous winter barley was the second most common sequence to follow winter barley, possibly reflecting the increase in cereal prices in recent years, particularly with regard to the premium for malting barley.

Table 6c is the most interesting of the set of three, consistently showing that the predominant crop sequence consisted of two cereal crops (almost always winter wheat) followed by oilseed rape, i.e. a three-course W-W-R ‘rotation’. This crop sequence was generally grown twice as often as the next most common sequence. However, this table, as with Tables 6 a and b, shows that most ‘rotations’ are variations on this theme and that there is no rigid pattern to crop sequences in England (and Wales, where data are available).

Crop frequency within the rotation

For each of the crops in the survey, the time gap between successive crops of the same species on the same site was analyzed (Tables 7a-c).

Table 7a. Per cent winter wheat crops with different time gaps since the last winter wheat crop, England and Wales (Wales included up to 2003 only).

	Harvest years						
No. of years gap	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
0	25.0	32.34	27.91	22.50	23.60	26.42	24.32
1	43.49	33.62	46.12	48.75	42.80	47.56	41.31
2	19.18	17.87	15.12	20.00	20.80	12.60	15.06
3	6.85	8.09	3.49	1.67	3.20	8.13	6.18
4 or more	5.48	8.09	7.36	7.08	9.60	5.28	13.13
Mean no. of years gap	1.243	1.259	1.163	1.221	1.324	1.183	1.425
Range*	0.75, 2	0, 2	0, 2	1, 2	1, 2	0, 2	1, 2

* lower and upper 25 percentiles

Table 7b. Per cent winter barley crops with different time gaps since the last winter barley crop, England and Wales (Wales included up to 2003 only).

	Harvest years			
No. of years gap	**2002**	**2003**	**2004**	**2005**
0	20.45	18.13	19.48	22.15
1	6.36	3.13	3.90	4.70
2	15.45	16.25	21.43	13.42
3	17.27	12.50	14.29	20.81
4 or more	40.45	50.0	40.91	38.93
Mean no. of years gap	2.509	2.731	2.532	2.497
Range*	1, 4	2, 4	2, 4	1, 4

* lower and upper 25 percentiles

Table 7c. Per cent oilseed rape crops with different time-gaps since the last oilseed rape crop, England and Wales (Wales included up to 2003 only).

	Harvest years						
No. of years gap	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
0	0	1.15	0	1.18	0	1.02	0
1	8.43	5.75	4.55	4.71	8.79	9.18	14.43
2	20.48	18.39	17.05	21.18	16.48	13.27	24.74
3	22.89	28.74	13.64	23.53	16.48	21.43	17.53
4 or more	48.19	45.98	64.77	49.41	58.24	55.10	43.30
Mean no. of years gap	3.108	3.126	3.386	3.153	3.242	3.204	2.897
Range*	2, 4	2.5, 4	3, 4	2, 4	2.5, 4	3, 4	2, 4

* lower and upper 25 percentiles

The Defra Agricultural and Horticultural Survey (2007) indicated that winter crops covered 69% of the total arable area cropped in England. Of this area, winter wheat accounted for 64% of the total area cropped under small grain cereals and this is clearly reflected in the frequent reoccurrence of winter wheat shown in Table 7a. The current practice of "short rotations" consisting of 2-3 crops including 1-3 winter wheats grown over a 2-4 year period can clearly be seen in Table 7a where the mean number of years between successive winter wheat crops ranged from 1.16 (2004) to 1.43 (2008) years. There was no clear temporal trend in the length of gaps between winter wheat crops.

Table 7b indicates that the situation for winter barley was different and highlights the use of winter barley as a 'non winter-wheat break crop', with the mean number of years between successive crops generally double that of winter wheat (ranging from 2.5 years [2005] to 2.7 years [2003]). In contrast with the winter wheat data in which between 81% (2008) and 91% (2005) of fields sown with winter wheat had previously been sown to the same crop within the past three years, only 38% (2003) to 45% (2004) of winter barley fields had been previously sown with winter barley within the same time period.

The data for winter oilseed rape crops indicate the important "break crop role" that the crop has within UK agriculture (Table 7c). In contrast with both winter wheat and (to a lesser extent) winter barley, winter oilseed rape was hardly ever drilled after winter oilseed rape, with the mean number of years between successive crops ranging from 2.9 years (2008) to 3.4 years (2004). As with Tables 7a and b, there was no clear temporal pattern to the data, although there was some evidence of an increased percentage of fields being sown with winter oilseed rape within 2-3 years of the previous crop (2006 onwards), i.e. there were more 'rotations' that were shorter (WWR or WRWR), as reflected in Table 6c.

France

Table 8 summarizes the main crop successions observed in France and including winter crops that were defined by experts (advisors from ACTA, *chambres d'agriculture*, agricultural ministry, researchers from INRA) according to geographical zone in France (Ecophyto R&D report Guichard *et al.*, 2009). Quantitative data are not available to express the proportion of the agricultural area occupied by each crop sequences. However, it can be noticed that these crop sequences are very diverse.

Table 8. Main crop sequences per region in France, according to local experts (Ecophyto R&D report; Guichard *et al.*, 2009).

Region	**Centre Poitou**	**Ile de France, Champagne-Ardennes, Bourgogne**	**Loraine, Alsace, Franche comté**	**Midi Pyrénées, Aquitaine**
Main crop sequence	wosr-ww-ww-wb wosr-ww-su-ww wosr-ww-su-dw-pe-ww ma-sb/dw ww-su-sb	wosr/pe-ww-sb/wb ma/beet-ww-ww/wb wosr-ww-pe-ww al-ww-beet/pot-ww	wosr-ww-w/wb wosr-ww-pe-ww ma-ma-ww su/wosr-ww-wb	ma-ww-su-w su-ww-wosr-ww
Region	**Nord-Ouest**	**Nord, Picardie, Normandie**	**Sud Est**	
Main crop sequence	ma-ww-ma-ww wosr-ww-wb-ma-ww	wosr-ww-wb/ww beet-ww-wosr/pe/li-ww pot-ww-li/pe-ww beet-ww-pot-ww-veg-ww/wb wosr-ww-pe-ww	ma-ww ma-ma-ww-wosr-ww	
Legend				
ww	winter wheat		sw	spring wheat
wb	winter barley		sb	spring barley
wosr	winter oilseed rape		sosr	spring oilseed rape
wbe	winter beans		sbe	spring beans
beet	sugar beet		ow	another winter crop
pot	potatoes		os	another spring crop
ma	maize			
su	sunflower		al	alfalfa
dw	durum wheat		li	linen
pe	peas		veg	vegetables

National statistical analyses on crop sequences are not available in France. However, field surveys are carried out by the ministry of agriculture every 5 years since 1994, and since 2006 it also accounts for the five years preceding the surveyed field. These data can be be extrapolated and allow us to give some overview about main crop sequences in France. Further quantitative analyses were therefore carried out on national 2006 data from AGRESTE (five-year surveys on agricultural practices, by region). Table 9 presents the proportion of the preceding crops for four main winter crops, winter wheat, winter barley, winter oilseed rape and potato.

Table 9. National average proportion of preceding crops for four winter crops (survey AGRESTE 2006, http://agreste.agriculture.gouv.fr/page_accueil_82/donnees_ligne_2.html).

	Preceding crop (% of the area of the given crop)					
	WOSR	**Wheat**	**Barley (and other cereals for wheat)**	**Maize**	**Beetroot**	**Other**
Winter wheat	22	15	7	24		32[a]
Barley	11	73		5		11[b]
WOSR		47	47			6[c]
Potatoes		66	8		8	18[d]

[a]Beetroot is included in this figure
[b]Barley and other cereals and beetroot are included in this figure
[c]WOSR, maize and beetroot are included in this figure
[d]WOSR and maize are included in this figure

The main crops planted before wheat were maize, winter oilseed rape and wheat. The wheat was the major preceding crop for barley (73%) as well as for potatoes (66%). Finally, the preceding crops for winter oilseed rape are cereals, with an equal distribution between wheat (47%) and barley (47%). It is important to notice that these proportions varied greatly between regions (see the online detailed data on the AGRESTE website, http://agreste.agriculture.gouv.fr/page_accueil_82/donnees_ligne_2.html).

To complete this quantitative data, analyses of crop successions over the 6 years (2001-2006) were carried out (Schmidt, 2009): the frequency of wheat, rape, cereals and spring crops were surveyed and are represented in the following table by the proportion of area concerned.

Table 10. Crop successions over 6 years (2001-2006) (Schmidt, 2009, data and funds provided by the statistical and prospective service from the French ministry of agriculture).

Frequency (number of years over 6 years)	**1**	**2**	**3**	**4**	**5**	**6**	**Number of surveyed fields**	**Area of surveyed fields (ha)**
% area with wheat	7.8%	26.0%	49.0%	13.7%	2.5%	1.0%	3448[a]	4188742[a]
% area with rape	23.7%	14.0%	1.3%	0.0%	0.0%	0.0%	3448[a]	4188742[a]
% area with rape (area in rape in 2006)	*30.9%*	*59.8%*	*9.1%*	*0.1%*	*0.0%*	*0.0%*	*1495*[b]	*987917*[b]
% area with straw cereals	4.7%	7.9%	36.7%	42.0%	6.9%	1.8%	3817[a]	4595424[a]
% area with spring crops	22.7%	27.8%	20.2%	3.1%	1.5%	0.0%	3817[a]	4595424[a]
Number of crop species over 6 years	**1**	**2**	**3**	**4**	**5**	**6**	**Number of surveyed fields**	**Area of surveyed fields (ha)**
% area with the given number of species	1.0%	22.8%	45.9%	27.8%	2.4%	0.0%	3817[a]	4595424[a]

[a]fields cultivated with wheat in 2006
[b]fields cultivated with rape in 2006
Minimum value, **Maximum value**

In almost 50% of the area surveyed (fields in wheat in 2006), wheat occurs every two years (3 years out of 6). It is important to notice that in 1% of cases, continuous wheat crop occurs over 6 years (Schmidt, 2009). On the same area, rape was cultivated one year out of 6 only on 22.7% of cases. On the other hand, almost 60% of the area cultivated with rape in 2006 was planted with winter oilseed rape every 3 years (2 years out of 6) and never occurred more than 4 years out of 6. Moreover, on almost 10% of the national area cultivated with rape in 2006, rape occurs at least every 2 years on average. More generally, cereal straws were present 4 years out of 6 on the surveyed area (fields in wheat in 2006), whereas spring crops were present from 1 to 3 years in average. Finally, the average number of crop species cultivated over 6 years was 3 different species, 5 species being very rare and 6 species never occurring. Based on these data, more frequent crop sequences were defined and are presented below. The total area is almost made up by just a few crop sequences (here 11 to cover 80% of the area; 38 crop sequences were found to cover the total area).

Table 11. More frequent crop sequences regarding spring crops, straw cereals and winter oilseed rape at the national level, based on 3448 surveyed fields, cultivated with wheat in 2006 (Schmidt, 2009, data and funds provided by the statistical and prospective service from the French ministry of agriculture).

Number of years with spring crops over 6 years	Number of years with straw cereals over 6 years	Number of years with rape over 6 years	Number of years with other crops over 6 years	% of area	Cumulating % of area
3	3	0	0	18.9%	18.9%
2	4	0	0	15.4%	34.3%
0	4	2	0	11.8%	46.1%
1	4	1	0	10.2%	56.3%
2	3	1	0	5.9%	62.2%
2	3	0	1	4.0%	66.2%
0	5	1	0	3.5%	69.7%
1	5	0	0	3.0%	72.7%
4	2	0	0	2.9%	75.6%
1	4	0	1	2.3%	77.8%
0	6	0	0	1.8%	79.7%

These results show two main types of succession based on the following patterns: one main crop and one straw cereal (29%), and one main crop and two straw cereals (40%). The main crops are mainly spring crops for short rotations. Continuous cereal crops occur on almost 2% of the French cultivated area, and straw cereals occur 5 years out of 6 on 6.5% of the area.

Finally, a typology of practices on oilseed rape was carried out: a multivariate analysis was done accounting for the frequency of straw cereals, oilseed rape among other variables. Four groups were identified and their characteristics are presented in Table 12, including some of the variables that were used in the statistical analysis, as well as other interesting variables, such as the frequency of ploughing ou TFI.

It is interesting to notice that these four groups are closely linked with the characteristics of the crop succession. For instance, the group with the lowest average TFI (group 3) is also the group with the more diversified crop succession (the lowest frequency of straw cereals and oilseed rape, but the highest frequency of spring crop. Other characteristics of IPM production appear in addition to crop succession diversification: lowest field area, lowest N rate (even if differences are low), highest delay of sowing, high frequency of ploughing and also lowest TFI on herbicide). This group also corresponds to the highest yield. However, it occurs on the lowest area. This group could be characterized as the IPM group.

On the other hand, the group 1, characterized by the highest average TFI on winter oilseed rape (and especially on herbicide and insecticide), correspond to the group with the highest frequency of winter oilseed rape and with the lowest frequency of spring crops. This group also corresponds to the lowest frequency of ploughing, to the highest amount of N fertilizer and to the highest field area (this can be linked to the lower frequency of ploughing). This group could be characterized as the intensive group but surprisingly, the yield is the lowest for this group.

Table 12. Results of the typology of crop protection cultural practices done on winter oilseed rape in 2006, regarding all pests, diseases and weeds (Schmidt, 2009, data and funds provided by the statistical and prospective service from the French ministry of agriculture).

	1	**2**	**3**	**4**	**National[1]**
Number of fields surveyed	**381**	**364**	**241**	**509**	**1495**
Proportion of fields surveyed	**25.5%**	**24.3%**	**16.1%**	**34.0%**	**100.0%**
Area	**5690**	**3778**	**2380**	**6030**	**17877**
Frequency of straw cereals (nb over 6 years)*	3.57	3.48	2.73	3.65	3.44
Frequency of oilseed rape (nb over 6 years)*	2.08	1.55	1.34	1.93	1.78
Frequency of spring crops (nb over 6 years)	1.47	1.82	1.83	1.62	1.67
Frequency of ploughing (nb over 6 years)*	1.39	4.85	3.95	4.32	3.64
Sowing date in comparison with the usual date (regional average, in two-week difference)*	-0.12	-0.07	0.38	-0.03	0.00
Sowing density (kg-1 ha-1)*	2.85	2.32	2.26	2.85	2.63
Total TFI*	6.88	6.21	5.42	6.78	6.45
TFI herbicides	2.04	1.50	1.54	1.88	1.77
TFI insecticides	3.29	3.07	2.41	3.24	3.08
TFI fungicides (mostly against sclerotinia)	1.02	1.18	1.12	1.09	1.10
Total N (kg^{-1} ha^{-1})	163	163	158	163	162
Yield (hkg^{-1} ha^{-1})	29.50	30.93	31.35	30.08	30.35
Field area (ha^{-1})	14.93	10.38	9.87	11.85	11.96

[1]TFI have been estimated only on the fields surveyed. TFI are therefore different from the table in the following section
***variables that have been used to determine the 4 groups of the typology**
Minimum value, **Maximum value**

These various cultural practice combinations highlighted by the multivariate analysis have different proportions in the different French regions. (Detailed data on each region can be found in Schmidt, 2009).

Treatment Frequency Indices for each country

Information has been gathered about pesticide usage in several countries, including information about treatment index in winter rapeseed and winter wheat in Germany, France, the UK and Denmark. Data from the four countries originate from different sources (UK: TFI data calculated or estimated from data supplied by The Food and Environment Research Agency, Sand Hutton, Yorks. Yield data from Defra Statistics (Department for Environment, Food and Rural Affairs). France: Ecophyto R&D report Guichard *et al.* 2009, Germany: DK: National statistic data on pesticides).

The way TFI values are calculated varies between the four countries. Denmark calculated TFI taking account separately of each active ingredient in any product. In the other three countries TFI is based on dose rates of complete products, even if the product contained more than one active ingredient (a method which was also used in DK up to 2000). Data based on rates of products rather than on standard doses of active ingredients will generally give rise to lower TFI values. (It is important to highlight the fact that some countries calculated their TFI based on data about real agricultural practices, e.g. the UK, whereas others (e.g. Denmark) calculate it based on selling of active ingredient)

Large differences in pesticide use between countries

There are clearly large differences in pesticide usage between the four countries, regardless of differences in method of TFI calculation, usage in Denmark being much lower than in the other countries. Since the various countries' starting points with regard to pesticide usage are very different, the potential for reducing usage will also vary. It should also be noted that in large countries there are marked regional differences. In Southern France, for example, they spray much less with fungicides than in Northern France due to fewer fungal disease problems.

The UK is the country with the highest usage in both winter wheat and winter oilseed rape. The reasons for such differences are not completely clear but several factors may be involved:

- More serious disease problems in the UK due to the mild wet winters associated with a maritime climate. This encourages fungal disease and facilitates the spread of virus by aphids.
- The use of full rates and of multiple products to combat herbicide resistance in the UK.
- The use in the UK of chemical weed control by large-scale agri-businesses rather than mechanical weeding which is more labour-intensive and energy-intensive.
- More risk-averse pest management practices in the UK
- The high priority given to maintaining crop yield in the UK, as well as profitability
- A less rigid policy framework for implementing pesticide usage reduction in the UK

As an example of the differences between countries, the UK has an average yield increase when using fungicides in wheat of 15 to 25 hkg^{-1} ha^{-1}. This means that UK farmers are concerned about yield loss and therefore often spray 3-4 times per season with fungicides, although often using 'split doses' where the full rate is applied over two occasions. By contrast, in Denmark the yield increase due to fungicides typically varies from 5 to 15 hkg^{-1} ha^{-1} in winter wheat. This indicates that Denmark has fewer disease problems than the UK and can therefore manage diseases with a lower use of fungicides.

Denmark's very low level of pesticide use compared to the other large grain-producing countries is partly due to the fact that Denmark has already incorporated many of the IPM elements in its cropping plans. The low pesticide usage is associated with many years' focus on maintaining a low usage level with the aid of several initiatives, including:

- Pesticide action plans that focus on intensive advice

- Using reduced dosages
- Using damage thresholds, regional warning systems and decision support systems
- Widespread use of resistant varieties

Table 13. Treatment Frequency Index in cereals and oil seed rape from four different countries.

Winter wheat	England 2006	France 2006	Germany 2007	Denmark 2007
Herbicides	2.43	1.4	1.9	1.33
Fungicides	2.26	1.6	1.9	0.64
Insecticides	0.96	0.3	1.2	0.2
Molluscicides	0.12			
Growth regulators	0.97	0.7	0.8	0.18
Total	6.74	4.0	5.8	2.34
Yield t^{-1} ha^{-1}	8.0	7.2	??	7.3

Oil seed rape	England 2006	France 2006	Germany 2007	Denmark 2007
Herbicides	2.19	1.8	1.6	1.2
Fungicides	1.49	1.1	1.0	0.3
Insecticides	1.22	2.8	2.3	1.2
Molluscicides	0.29			
Growth regulators	*	0.4	0.5	0
Total	5.19	6.0	5.5	2.7
Yield t^{-1} ha^{-1}	3.4	3.0		3.5

* The choice of fungicide can be influenced by any additional growth regulatory effect

Winter barley	England 2006	France 2006	Germany 2007	Denmark 2007*
Herbicides	1.97	1.44	1.5	1.33
Fungicides	1.32	1.32	1.1	0.5
Insecticides	0.82	0.2	0.7	0.2
Molluscicides	0.02			
Growth regulators + others	0.63	0.56	0.6	0.05
Total	4.76	3.52	4.1	2.0
Yield t^{-1} ha^{-1}	6.6	6.8		5.8

* Estimated based on winter cereal statistics

Spring barley	England 2006	France 2006	Germany 2007	Denmark 2007
Herbicides	1.51	1.16	No data	0.99
Fungicides	1.01	1.05	No data	0.32
Insecticides	0.14	0.1	No data	0.3
Molluscicides	0.01			
Growth regulators	0.14	0.46	No data	0.04
Total	2.81	2.77		1.67
Yield t^{-1} ha^{-1}	5.1	5.9		4.9

References
DK: Miljøstyrelsen: Bekæmpelsesmiddelstatistikken
Germany: JKI: Network of reference farms for plant protection – Annual report,
UK: TFI data calculated from data supplied by The Food and Environment Research Agency, Sand Hutton, Yorks. Yield data from Defra Statistics (Department for Environment, Food and Rural Affairs).
France: Ecophyto R&D report Guichard *et al.*, 2009

DEXiPM and links to RA2.6a

DEXi-PM has been developed for the assessment of sustainability of current and innovative cropping systems proposed by system case study groups in ENDURE. It is a hierarchical qualitative multi-criteria model supported by the software DEXi. It consists in a decomposition of the overall sustainability into more and more specific criteria, starting with environmental, social and economic sustainability. A tree of criteria has been chosen by experts, according to their relevance in terms of sustainability assessment. Criteria are qualitatively estimated, and aggregated with if-then decision rules (to determine the value of a criterion depending on the value of the immediate descendant criteria). Decision rules can be fixed according to scientific data or expertise, or adaptable by the user according to priorities or context. The importance of each criterion is characterized by weights. The model is presented in the deliverable DR 2.14.

DEXiPM is used to estimate a final score for sustainability for the systems assessed, but can also be used as an 'instrument panel' for the sustainability of the system, giving estimated indicators for each aggregated criterion. It therefore provides good visibility for all aspects of the sustainability of a given system. The aim is to provide a framework for discussions around the proposed systems and help the system case study to analyze the advanced and innovative systems proposed. The model is still under development and may need to be improved according to the feedback from the system case study groups (maize and winter crops based cropping systems).

Proposals of AS and IS1 systems for each country

Overview of the crop rotations proposed with calculations on TFI

Country	Systems	Rotation	Average annual TFI
DK	CS	W. barley – W. rape – W. wheat – W. wheat	2.5
	AS	I. W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley	1.78
		II. W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop / undersown ley – S. barley	1.68
	IS	I. W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley	1.65
		II. W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop / undersown ley – S. barley	1.57
France	CS *Bassin Parisien*	Sugarbeet-winter wheat-winter oilseed rape-winter wheat	7.2
	IS *Bassin Parisien*	(Mustard)-Sugarbeet-Winter Wheat-(Mustard)-Hemp-Winter Wheat-Winter Oilseed Rape-Winter Wheat	1.9
	CS *Poitou Charentes*	Winter oilseed rape-winter wheat-winter barley	5.8
	AS *Poitou Charentes*	Winter oilseed rape-winter wheat-winter barley-(intermediate legumes)-sunflower-winter wheat	2.2
	CS *Bourgogne*	Winter oilseed rape-winter wheat-winter barley	7.1
	IS *Bourgogne*	Winter oilseed rape-winter wheat-spring barley-alfalfa-alfalfa-winter wheat-(Mustard)-sunflower-triticale	0.4
UK	CS	W. wheat – W. wheat – W. rape	6.2
	AS	I W. wheat – S. beans – W. wheat – W. rape	4.3
		II W. wheat – S. beans – W. wheat – S. wheat – W. rape	4.2
		II W. wheat – S. beans – W. wheat – S. barley – W. rape	3.8
	IS1	IIIS W. wheat – S. beans – W. wheat – S. wheat – W. rape	3.4
		IIIS W. wheat – S. beans – W. wheat – S. barley – W. rape	3.2
		IIIF W. wheat – S. beans – W. wheat – Fallow – W. rape	3.1
		IVS W. wheat – S. beans – S. wheat – W. rape	3.0
		IVS W. wheat – S. beans – S. barley – W. rape	2.7
		IVF W. wheat – S. beans – Fallow – W. rape	2.7

Denmark

AGRICULTURAL CONTEXT

Site: Denmark – relevant for most soils and climates throughout the country

Soil and climate: sand, sandy loam and loam soils predominate. Flat, slightly undulating/sloping and hilly fields create a diverse mosaic of the Danish agricultural landscape. Precipitation is evenly distributed over the year with an yearly average of 712 mm for the country. The average temperature is 7.7°C. There is a high risk of leaching from sand and sandy soils during the winter period. Risk of soil erosion is generally low apart from steep fields where some surface run-off soil materials may occur.

Regional context: intensive crop and pig production, low proportion of non-productive area

Specificity of the farm where the system is proposed: rotations of relevance for pig production. Inverting tillage most commonly used. Perennial weeds are controlled regularly and occur at low levels. Wild oats are hand weeded. Certified seeds are used in about 90% of the sown area of cereals.

CURRENT SYSTEM

Crop sequence: W. barley – W. rape – W. wheat – W. wheat

Crop protection strategy: pesticides

Main pest risk: autumn emerging weeds (all crops), especially grass weeds. Weevil, pollen beetle (WOSR), aphids (cereals), rust, mildew, septoria, net-blotch

Expected yield given the context: medium to high

ALTERNATIVE CROPPING SYSTEM (AS) / INNOVATIVE SYSTEM (IS1)

Proposed crop sequence for AS/IS1 prototype:

I. W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley

II. W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop / undersown ley – S. barley

The two crop rotations proposed constitutes the framework of the Danish suggestions for AS and IS1. The spring-sown crops in a row in rotation II. are expected to suppress annual grass weeds and cleavers (*Galium aparine*) more strongly than rotation I. resulting in a lower need for gramicides. Both rotations are considered for supplying the farmer with sufficient amounts of fodder crops and are thus competitive with current crop rotations typically having even more winter cereals in the rotation. The TFI is already low.

Please note that the AS and IS1 systems are all presented in detail in Appendix A.

LIST OF MAJOR TOOLS USED FOR PESTICIDE REDUCTION IN THE AS SYSTEM

- Inclusion of spring barley in the crop rotation
- Stubble cultivation
- Crop varieties with disease resistance
- Delayed sowing of winter wheat
- Reduced pesticide doses based on decision support systems
- Optimized timing of pesticide application
- Extensive use of warning systems to determine the need for pesticide application
- Inter-row cultivation in winter oil seed rape
- Nutrient placement in spring barley

LIST OF DIFFERENCES BETWEEN AS AND IS1

Both AS and IS1 systems are based on the same crop rotation compositions, which is explained by the need to supply pig producers with sufficient cereal fodder. The major differences between the two systems are thus the measures and tools used in each crop in the rotation.

The new tools to be implemented in IS1 are listed below:

- Optimization of systems to manage logistics at farm level: improves timing, capacity and rounding off of areas because the work is better organized
- Spraying equipment with higher capacity
- Precision agriculture: GPS systems to avoid overlapping, 5% savings in pesticide use in Danish farm test. Weed mapping and patch spraying whenever possible
- Variety mixtures: minimizes disease attack relative to single varieties provided that the varieties are available. Avoid high disease levels
- Species mixtures: winter wheat and winter pea mixtures, less disease attacks in wheat, less aphid attack. Weed problems more uncertain
- Trap cropping. Flowering bordering zones to trap insects
- Better decision support systems. There is still considerable room for improving current systems
- Improved forecasting models, especially against septoria and aphids. These models should be integrated with decision support systems
- Mechanical weeding in cereals: only relevant, if no herbicides are available or extremely restricted
- Landscape management: diversification schemes of crops not seen as a useful tool for practical use.
- Margins management: undesired weed seed spread may occur from cultivated field boundaries creating room for the growth of annual weed species. However, margins can act as barriers for the spread of especially perennial weeds if the boundaries are cultivated frequently enough to prevent weed seed production and vegetative spread of perennials. Beneficial for insect control, margins serve as a barrier and reservoir for predating insects.
- Stewardship schemes
- Harvesting techniques: collecting weed seeds during harvest operation, spot mapping of individual weed species during harvest operation to support subsequent patch spraying in subsequent years (especially mapping thistles and couch grass appears relevant in this context)
- Development of band-spraying techniques against intra-row weeds in oilseed rape
- Adjusted fungicide dosage according to crop biomass
- Soil management: adjusted according to need and problem. Inversion tillage can be avoided in some years

TFI ANALYSES

Table 14 shows the TFIs for herbicide, fungicide and insecticide uses in the individual crops included in the current systems (CS), AS and IS1 systems. The TFIs for AS and IS1 are based on experts judgements of the needs. In contrast to the TFI calculations for France and the UK, the Danish TFIs are based on active ingredients.

Table 14. TFIs for herbicide, fungicide and insecticide uses in each crop included in the current (CS), AS and IS1 systems.

Based on 2007 data		**TFI CS**	**ASI**	**ASII**	**IS I**	**IS II**
Herbicides	w. barley	1.33	1	1	0.95	0.95
	w. oil seed rape	1.2	0.5	0.5	0.5	0.5
	w. wheat	1.33	1	1	0.95	0.95
	w. wheat	1.33	1.2	1.2	1.1	1.1
	spring barley		0.7	0.7	0.65	0.65
	spring barley			0.7		0.65
Fungicides	w. barley	0.5	0.4	0.4	0.4	0.4
	w. oil seed rape	0.3	0.2	0.2	0.2	0.2
	w. wheat	0.64	0.6	0.6	0.5	0.5
	w. wheat	0.64	0.6	0.6	0.5	0.5
	spring barley		0.25	0.25	0.25	0.25
	spring barley			0.25		0.25
Insecticides	w. barley	0.2	0.2	0.2	0.2	0.2
	w. oil seed rape	1.2	1.2	1.2	1	1
	w. wheat	0.2	0.15	0.15	0.15	0.15
	w. wheat	0.2	0.15	0.15	0.15	0.15
	spring barley		0.25	0.25	0.25	0.25
	spring barley			0.25		0.25
Growth regulator	w. barley	0.05	0	0		
	w. oil seed rape					
	w. wheat	0.2				
	w. wheat	0.2				
	spring barley					
	spring barley					
Round up		0.5	0.5	0.5	0.5	0.5
Total		10.02	8.9	10.1	8.25	9.4
For rotation		**2.5**	**1.78**	**1.68**	**1.65**	**1.57**

DEXiPM ANALYSES
Current system (CS): W. barley – W. rape – W. wheat – W. wheat
Alternative system (AS): W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley
Innovative system (IS1): W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop/undersown ley – S. barley

Context of the analysis
For the comparison of the systems it is assumed that the farmer is a pig producer with a sandy soil type. As mentioned previously, this increases the risk of leaching during the winter period. Risk of soil erosion is generally low apart from steep fields where some surface run-off of soil materials may occur. It is assumed that this is not a problem for this comparison.

Inputs to DEXiPM
In order to give a detailed background of the comparison of the Danish systems, the following table presents the inputs and comments on the choice of input. When looking at the inputs, it becomes

obvious that there are not major overall differences between the inputs of the three systems. This is, however, due to the choice of rotation. They are chosen because they can be implemented in a Danish context without major obstacles to the Danish farmers (besides economy).

Option	Current system	Alternative system	Innovative system	Comment
Leaching risk (soil and climate)	Very high	Very high	Very high	Fixed for comparison
Runoff risk due to context	Low	Low	Low	Fixed for comparison
Field erosion risk due to context	Low	Low	Low	Fixed for comparison
Hydromorphic soil	No	No	No	Fixed for comparison
Potential yield	Medium to high	Medium to high	Medium to high	Fixed for comparison – assumed that the potential yield is in relation to the specific system. If it is marketable yield, AS and IS should be lower.
Regional intensification	Not favourable to biodiversity	Not favourable to biodiversity	Not favourable to biodiversity	Assumed that the area is mainly open-field
Availability of uncropped land	Very low	Very low	Very low	In pig producing areas of DK
Non-productive areas	Low proportion	Low proportion	Low proportion	In pig producing areas of DK
Average market price	Low to medium	Very low	Very low	The farmer will not earn the same amount of money from spring cereals as from winter cereals
Labour hourly wage	Very high	Very high	Very high	The wages in DK are generally very high compared to the rest of EU
Local availability of water for irrigation	High	High	High	There are currently no restrictions to water use
Financial security of the farm	Medium	Low	Low	Implementing the AS and IS-systems will reduce the income of the farmer and thereby the financial security
Number of crops	Medium to low	High	High	See the description of the systems
Proportion of summer, late-harvest crops	Very low	Very low	Very low	Currently not relevant for a pig producer (climate, fusarium etc.)
Crop type	1 type	3 types	3 types	Winter, spring and catch crops
Crop effect on pollinators	Little favourable	Little favourable	Little favourable	Due to oilseed rape. Catch crops are not important in this case due to late establishment
Additional seed cost of crop species or cultivars	No	Moderate	Moderate	Catch crops cost money
Sowing density	Medium	Medium	Medium	Will not be changed significantly by the farmers
Soil cover	High	High	High	In all rotations fields are green in more than 61% of the year
TFI of insecticide	0.45	0.39	0.33	For the CS, official data are available. Other data are estimated based on expert knowledge
TFI of fungicide	0.52	0.41	0.35	
TFI of herbicide	1.30	0.88	0.80	
Total Pesticide TFI	2.51	2.18	1.98	
Pesticide mobility	High to medium	High to medium	High to medium	Worst case due to sulfonylureas
Pesticide eco-toxicity	Medium to low	Medium to low	Medium to low	Due to the strict approval system
Soil cover at pesticide application	High	High	High	This input only makes sense for herbicides under DK conditions
Mineral N fertilizer applications	Low	Low	None	Intensive pig producers apply N as slurry. Catch crops reduces the allowed amount, therefore none in the IS
Organic N fertilizer applications	High	High	High	Slurry
Organic amendments	Very low/none	Very low/none	Very low/none	
Coverage of crop Nitrogen requirement	Balanced	Balanced	Balanced	On average 10% below economical optimum
Mineral P fertilizer applications	None	None	None	Due to P in the slurry
P surplus	Low	Low	Low	Due to the limitations in N, it usually fits with the recommendations
Mineral K fertilizer applications	None	None	None	Due to K in the slurry
Total number of treatment operations	4-7	4-7	4-7	3 sprayings and 1 time fertilizer as a minimum (winter barley). Maximum 6 sprayings and 2 times fertilizer (oilseed rape), therefore the average is between 4-7
Deep tillage	Every year	Every year	Every year	Due to the benefits on weeds in particular
Inversion tillage	With inversion	With inversion	With inversion	
Superficial tillage in the crop (mechanical weeding)	None	1 per year	1 per year	Only relevant in OSR, but need graduation
Superficial tillage between crops (including false seedbed)	1-3 per year	1-3 per year	1-3 per year	Rather 1 than 3
Irrigation	High	High	High	Due to the soil type
Risk of water stress	Medium	Medium	Medium	Compared to other parts of Europe it is low, but compared to other Danish soils it is high
Fuel consumption at harvest	Medium	Medium	Medium	Need values? What is low? Which data are behind this?
Stubble/straw management	Exported or burnt	Not exported	Not exported	If there is money in the straw, or it is used for bedding, it is exported. Often it is chopped. Burning not allowed
Capacity of crop sequence to uptake N during the leaching period	Medium to low	High to medium	High to medium	Due to increasing use of catch crops

Yield reduction due to system, other than nutrition and pests or weeds	No	Medium	High	Due to choice of other species. Spring barley yields less than wheat and has lower nutritional value
Habitat management	None	None	None	Not possible with the low amount of non-cropped area
Habitat management quality	None	None	None	
Pest control	High	High	High	All systems will provide the farmer with satisfactory control
Number of hours	Medium to low	High to medium	High to medium	Increased time needed for monitoring etc.
Risk of simultaneous operations, due to a limited number of suitable days	Medium	Low	Low	In the system based on winter crops, the risk is higher due to the fact that all operations have to be performed within a short period.
Physical difficulty and disturbance	Low	Medium	Medium	More difficult in the more complex systems. Maybe not so different in these 3 cases
Heavy metal contamination	None	None	None	Not relevant in these systems
Proportion of gross margin due to main crop	High	High	High	All crops are considered main crops and no crops can be left out due to the need for fodder.
Risk of pesticide residuals in product	None	None	None	Due to the strict approval system in DK
Risk of mycotoxin contamination	None	None	None	
Production risk	Medium	Low	Medium	The current practice is leading to uncontrollable problems in the future, the IS gives higher risk of production
Pest pressure	Medium	Low	Low	The AS and IS should provide a better protection from the beginning
Quantity of rain during late harvest	High to medium	High to medium	High to medium	Impossible to estimate, varies from one year to another
Requirement for agricultural equipment	Low-none	Low-none	Medium	IS may require investment in equipment for mechanical weeding
Risk of pesticide drift due to material	Low or no application	Low or no application	Low or no application	Use of low-drift nozzles and other factors is implemented in all arable rotations
Farmers' and employees' knowledge and skills	Low	Medium	High	The IS requires increased awareness and knowledge by the farmer and employees
Affiliation to a farm support network	Affiliation to a network corresponding to the strategy	Affiliation to a network corresponding to the strategy	Affiliation to a network corresponding to the strategy	DAAS is capable of supplying the advice needed, also for starting farmers groups where relevant
Availability of relevant advice for the strategy	High	High	High	
Environmentally based direct subsidies in support of the strategy	None	None	None	There are currently no such subsidies available for the suggested systems
Non-environmentally based direct subsidies in support of the strategy	None	None	None	
Access to relevant technologies	Easy	Easy	Possible	Most operations, also in the IS systems can be made with already available material
Delivery constraints	None	None	None	Most of the produced will be used for fodder on-farm
Compatibility with technological/aesthetical requirements	High	High	High	It is assumed that all crops will meet the required standard needed for fodder, oil, etc.
Compatibility with certification requirements	No certification requirement	No certification requirement	No certification requirement	Assuming that all crops are used on farm except WOSR which is assumed to be able to meet the requirements
Valuation or devaluation of price due to crops in the crop sequence	Neutral	Neutral	Neutral	No change in the amount of cash crops
Valuation or devaluation of price due to quality and certification requirements	Neutral	Neutral	Neutral	It is still assumed that the WOSR will meet the requirements needed. All other crops are used for fodder
Reluctance/reservation of the farmer to adopt the strategy	None	Yes	Yes	The farmers use the CS because it gives them the highest profit (money and fodder)
Social accessibility of product for consumers	Accessible	Accessible	Accessible	Really only a problem for WOSR
Societal value of landscape	Indifferent	Indifferent	Good	Higher proportion of catch crops MAY improve the perception of the landscape
Acceptability of the strategy by society	Indifferent	Indifferent	Indifferent	Society is never involved in the strategies

Analysis and discussion

In Figure 1 the overall sustainability of the three proposed systems is shown. The results indicate that the overall sustainability is lower for the Alternative and Innovative systems, compared to the Current system.

The reasons for these differences should be found in the underlying attributes forming the basis for the overall sustainability (the economical, social and environmental sustainability). These 3 attributes are shown in Figure 2. Apparently the suggested cropping systems have the same impact on the environmental and social sustainability. Looking at the input affiliated with the social sustainability, this is however not surprising, as they are supposed to be the same for all three systems.

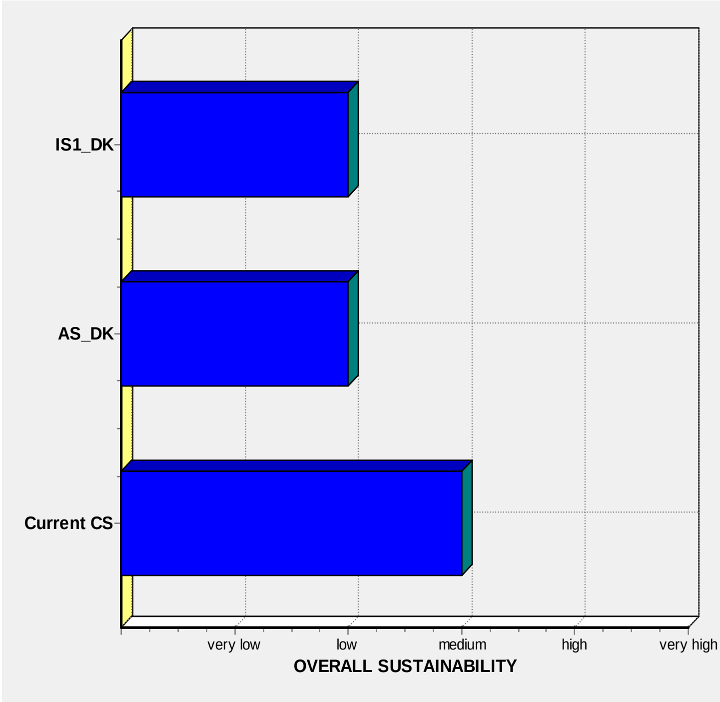


Figure 1. Overall sustainability of the proposed Danish systems.

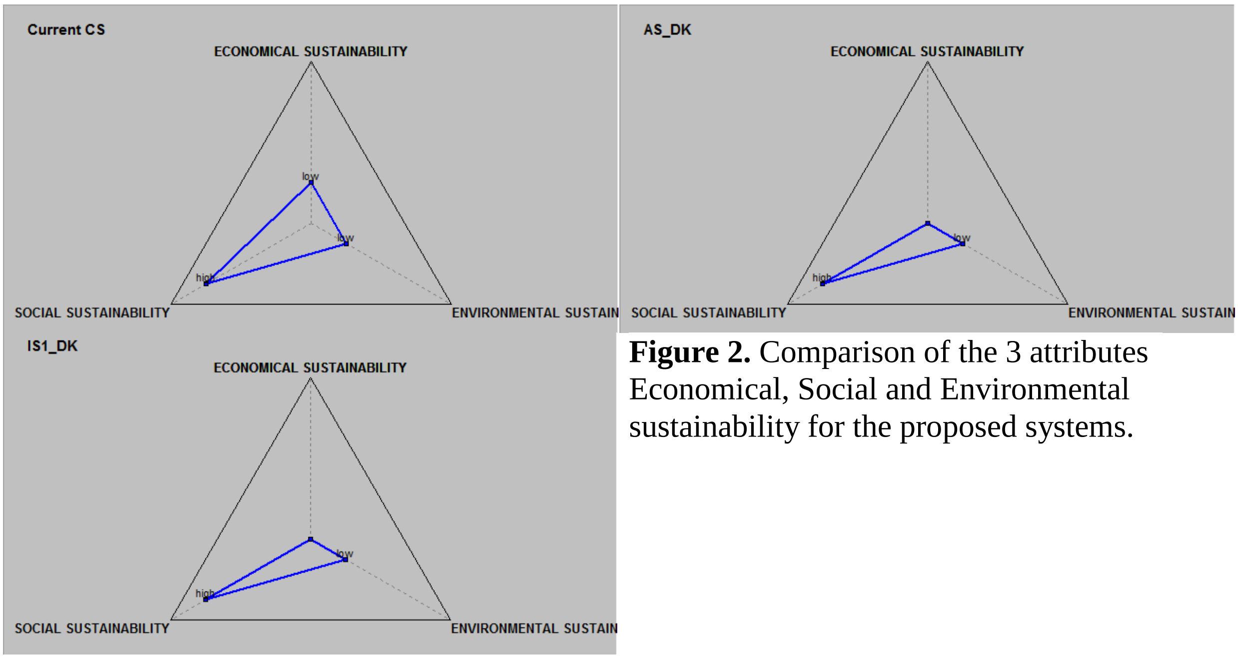


Figure 2. Comparison of the 3 attributes Economical, Social and Environmental sustainability for the proposed systems.

Of highest importance to the farmer is the economy and environment. These two aspects will therefore be analyzed separately in the following sections.

Economical sustainability
As shown in Figure 1, the overall sustainability is lower for the AS and IS systems compared to the current CS. By looking at Figure 2, the reason for this must be found in the economical sustainability, as the environmental and social sustainability are the same for the 3 systems. The economical sustainability is made up by the two attributes Profitability and Viability. The profitability is very low for all three rotations, whereas the viability is medium for the current system and low for the AS and IS systems. Looking at the two attributes separately reveals that even though the profitability apparently is very low for all three systems, the yield is higher for the CS and AS, and the selling price is higher for the CS system, due to the higher production value. In Figure 3, the costs (except labour) are compiled. The costs are more or less similar for the three systems, although the costs of pesticides are lower in the IS system compared to the other two systems and the costs of seeds higher in the alternative systems than the Current CS (due to increased amount of catch crops).

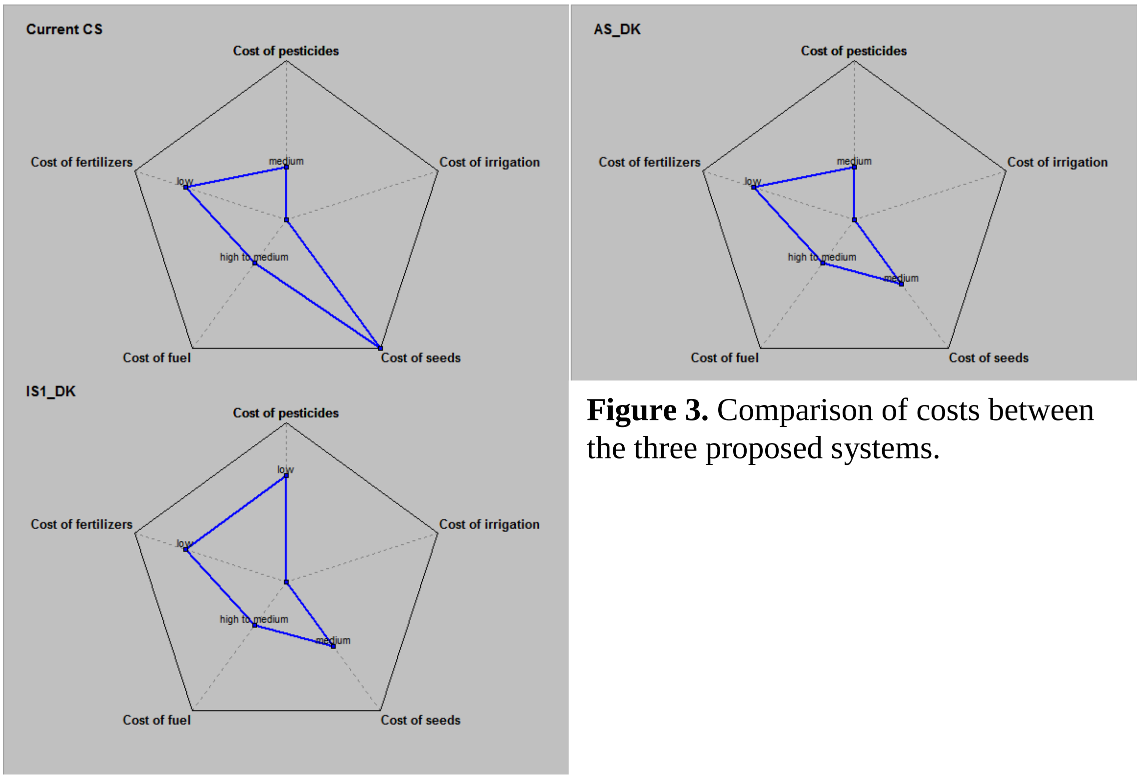


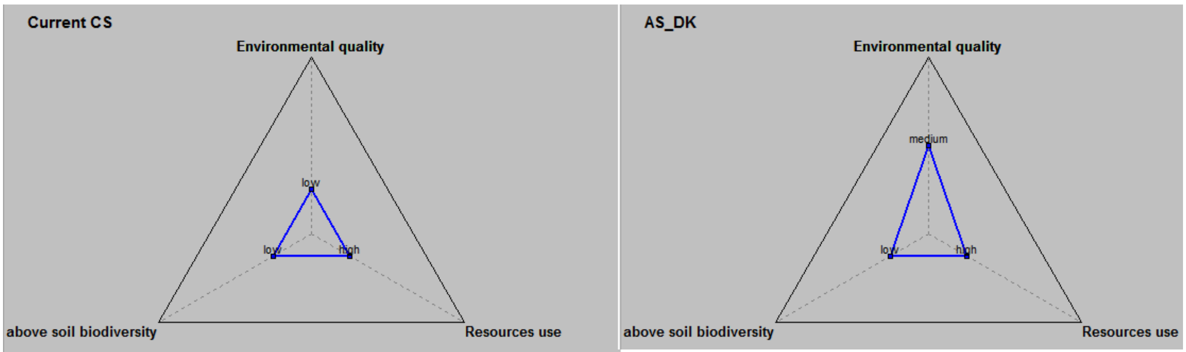
Figure 3. Comparison of costs between the three proposed systems.

Apparently, the reason why the profitability is the same for the three systems is the shifted balance between incomes and costs. What is saved in pesticides is lost in yield and vice versa. It is not clear why this is the case. Maybe the underlying attributes are not sensitive enough to include all aspects of the systems. However in practice, the current system has the overall advantage of providing the farmer with a higher and stable yield for feeding the pigs and thereby increasing the gross margin and the profit. The money is not only made in the field.

The viability of the systems is lower for AS and IS systems than for the Current CS. This is, according to DEXiPM, due to a higher investment capacity of the Current CS compared to the AS and IS systems. As mentioned in the input-table, this is a result of the increased production risk in the AS and IS systems due to the changes made to the cropping system. This could be visualized by including one crucial input factor in DEXiPM, and that is the overall gross margin of the farm. In Denmark an analysis of the farm economy shows that first and second year wheat always gives the highest profit to the farmer, even when it is corrected for the pre-crop value (e.g. winter oilseed rape is a better pre-crop than wheat). With spring barley giving a significantly lower profit, it requires convincing arguments, e.g. uncontrollable pest problems, regulation, lower availability of pesticides, etc. to convince the farmer to change practice. An example under Danish conditions is the control of *Vulpia myuros* (Rat's-tail Fescue). It is not easy to control with the approved herbicides, and rapidly becomes a massive problem in winter crop-based cropping systems. This problem has convinced several farmers to change their crop rotation and management practice.

Environmental sustainability

Even though the proposed AS and IS systems should have a positive impact on the environment compared to the current CS, there are no differences in the environmental sustainability. Looking at the inputs, there are also not many differences. The pesticide use is, however, lower in the AS and IS systems compared to the current CS. In Figure 4, the three attributes making up the environmental sustainability are presented. It is evident that the environmental quality is the parameter making up the difference in the environmental sustainability, with the quality being higher in the AS and IS systems.



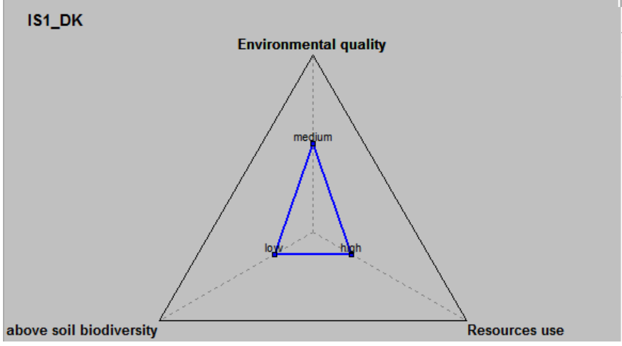


Figure 4. Comparison of the three parameters making up the environmental sustainability of the proposed cropping systems.

The environmental quality consists of 3 attributes, i.e. water quality, soil quality and air emissions. The only parameter showing any difference between the systems is the water quality, being higher for the AS and IS systems than for the current CS (data not shown). Water quality is again composed of 3 attributes, i.e. eutrophication potential, groundwater quality and aquatic ecotoxicity. Whereas both the AS and IS systems has a lower eutrophication potential than the current CS, only IS has a lower aquatic ecotoxicity (data not shown). The difference in eutrophication potential occurs due to a lower nitrate leaching from the AS and IS systems. This is due to the fact that the input termed "Capacity of crop sequence to uptake N during the leaching period" is differentiated between the three systems as a consequence of the positive impact of the catch crops. The difference in aquatic ecotoxicity originates from the difference in the input "Total pesticide TFI", which is one level lower for the IS system compared to the AS and CS. It is, however, surprising that the model is not able to simulate the rather large decrease in TFI between the CS and AS systems. The sensitivity of the model clearly needs to be improved, as the large decreases in total pesticide use have already been made in Denmark.

It should be noted that the inputs made for the comparison is to a large extent based on qualitative estimates. The results of the comparison should therefore not be used to choose one system over another, but rather to uncover relevant questions for the user. Therefore, the ability of DEXiPM as a tool to evaluate the performance of different crop rotations is limited. As long as the inputs are based solely on the perceptions of individual persons, and not data, it is difficult to draw reliable conclusions from the model.

Conclusion
The suggested alternative and innovative systems proposed are not very different from the current practice. This is a deliberate choice, as the primary goal of the Danish farmers is to run a profitable farm with the least risk to the production. Especially for the pig producers, it is of primary importance that the cropping system is capable of supplying sufficient food for the pigs. On average, spring barley yields 10% less than a winter wheat. Furthermore, the nutritional value of spring barley is lower than for wheat. Replacing spring barley with another crop is not possible, as the only two alternatives are spring wheat and oats, which both gives lower yields than spring barley.

Based on the inputs given, it is concluded that the proposed AS and IS systems are beneficial to the environment, more specifically the leaching of nutrients and the use of pesticides (only for the IS system). It is however also concluded that although the profitability remains the same for the three systems, the viability of the AS and IS systems decreases. Under the current financial situation in Europe, it is unlikely that the farmers want to/will be allowed to change their practice into a more risky production. The motivation to implement a more IPM-like approach should therefore come from another source (subsidies, changes in CAP instruments, pesticide taxes, regulations, uncontrollable problems, new markets (e.g. fibre or fuel crops), etc).

UK

- **Context**
  - **Site:** main predominantly arable area of England
  - **Soil and climate:** clay and clay-loam with maritime climate
  - **Regional land-use context:** predominantly arable
- **Current system**
  - **Crop sequence**: winter wheat - winter wheat - winter oilseed rape
  - **Crop protection strategy**: pesticides and cultural control
  - **Main pest risk**: grass weeds especially black grass/bromes (all crops), aphids / virus (WW/WOSR), flea beetle and pollen beetle (WOSR), slugs, pigeons, fungal diseases, especially Septoria (resistance)/yellow rust, phoma/light leaf spot/sclerotinia on OSR.
  - **Expected yield given the context**: national average or above
- **Alternative system**

Proposed crop sequences for AS
Improving environmental sustainability, spreading the workload, black grass containment, better disease and pest management by reducing presence of cereals in rotation, breaking ‘green bridge’ between cereals (take-all, virus), and more years between OSR crops:

Rotation I, four-year, high proportion of first wheat crops:

winter wheat
spring beans
winter wheat
winter oilseed rape

Rotation II, five-year, more spring crops:
winter wheat
spring beans
winter wheat
spring milling wheat / spring malting barley
winter oilseed rape

Innovative system 1

Proposed crop sequences for IS1
Further improving environmental sustainability and potential for spreading the workload, potential for fallow and/or increased proportion of spring-sown crops for increased black grass containment and better disease and pest management.

Rotation III, five-year, wider choice of spring crops, option of fallow:
winter wheat
spring beans (or other non-brassica dicot spring crop)
winter wheat
spring milling wheat / spring malting barley / fallow
winter oilseed rape

Rotation IV, four-year, smaller proportion of first wheat crops, higher proportion and wider choice of spring crops, option of fallow:
winter wheat
spring beans (or other non-brassica dicot spring crop)
spring milling wheat / spring malting barley/ fallow
winter oilseed rape

Please note that the AS and IS1 systems are all presented in details in Appendix A.

LIST OF MAJOR TOOLS USED FOR PESTICIDE REDUCTION IN THE AS SYSTEM FOR THE UK

System-wide tools
1. Crop sequence:
    - Introduction of spring crops and greater taxonomic variety of cropping for pest management particularly containment of grass weeds, especially black grass. Provide overwinter stubbles for predators of invertebrate pests and weed seeds, including birds. Break ‘green bridge’ for cereal pests and diseases.
    - Lengthening the rotation: more years between OSR crops to help disease control
2. Pesticide targeting and resistance management:
    - Ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems (implementation of available tools).
3. Tillage:
    - Minimize tillage and chop straw wherever possible to conserve natural enemies associated with soil and to conserve energy
    - Consider ploughing for grass weed management before a second cereal
    - Before spring crops plough if necessary in spring (in autumn on heavy land) to create seedbed and to control weeds.

4. Habitat management for conservation biological control, providing non-crop refugia and resources for natural enemies of invertebrate pests:
- Field scale:
  - provide overwinter stubbles,
  - minimize tillage,
  - beetle banks,
  - wild flower margins,
  - grassy margins,
  - hedges.
- Landscape scale:
  - maintain spatial and temporal diversity of cropping;
  - rotations including an entomophilous crop (e.g. WOSR, spring beans);
  - diversity of non-crop areas, e.g. woodland, game cover;
  - high connectivity of non-crop habitats to facilitate movement of natural enemies.

Tools for different pest groups

Weed management:
- Use higher seed rates and cultivars with strong competitiveness where weeds are problematic
- Spot mapping and targeting of weeds

Disease management:
- Use of resistant cultivars

Invertebrate pest management:
- Habitat management for conservation biological control (see above)
- Minimize tillage to conserve natural enemies
- Use of resistant cultivars
- Plough for slug control

LIST OF MAIN DIFFERENCES BETWEEN AS AND IS1 FOR THE UK

- Widening the choice of dicot break crops (e.g. peas, linseed, other minor crops) to diversify crop taxa, reduce pest pressure and foster diversity of natural enemies.
- Option of increasing the proportion of break crops in the rotation.
- Option of introducing a fallow where management of grass weeds is particularly difficult.
- Drilling OSR into wide-rows (~50 cm) to minimize tillage and enable:
  - inter-row weed management (mechanical weeding where herbicide resistance is a problem, or targeted herbicide)
  - targeted nutrient application to avoid fertilizing weeds
  - potential for targeted applications of other pesticides
- GPS – controlled traffic system to save fuel and carbon emissions, reduce soil compaction and crop damage
- GPS – controlled pesticide applications for accurate pesticide targeting and stewardship, reducing TFI
- Trap cropping for pest management in oilseed rape
- Improved and new decision support systems
- New resistant crop cultivars

TFI ANALYSES ON AS AND IS1 SYSTEMS

Derivation of TFIs and TFI reductions

The baseline for the UK study is practice in England in 2006. TFIs for CS are calculated from Pesticide Usage Survey (PUS) 2006 data for England supplied by The Food and Environment Research Agency (Fera), or are estimated from PUS data for 2006. TFIs for AS and IS1 rotations are calculated according to TFI reductions estimated to be associated with the practices proposed for each system. TFI reductions are estimated on the basis of expert knowledge and, for insect pests, PUS data and Crop Monitor data for 2006 (Central Science Laboratory and Home Grown Cereals Authority). These estimates are itemized in the 'Crop protection strategy' tables for the UK in Appendix A (N.B. the percentage reductions are not additive but cumulative; they are applied successively to the TFI associated with CS values to produce the figures given in Table 15).

Estimates of TFI reductions are intended to be conservative. For example, although there is good evidence for the influence of habitat provision in the landscape on numbers of natural enemies there is much less data on the effects on pest numbers and crop damage. This effect is therefore conservatively estimated as a 10% reduction. The effects of changes in crop sequence and landscape are estimated but no additional allowance is made for any cumulative effect over time that might be expected. Seed dressings are not included in this study. The recent introduction of neonicotinoid insecticide seed dressings may allow further reductions in TFI of insecticide sprays.

Note that in IS1 it is expected that fallow would be employed only when grass weed management and/or resistance is an urgent problem. For this reason the baseline herbicide use for fallow fields is estimated to be two total herbicides.

Table 15. TFIs for all pesticide groups for each crop included in the UK current (CS) and proposed alternative (AS) and innovative (IS1) systems .

System	Crop	All pesticides	Herbicide	Insecticide	Fungicide	Molluscicide	PGR*
CS	W. wheat	6.74	2.43	0.96	2.26	0.12	0.97
	S. wheat	4.42	1.51	0.43	1.5	0.01	0.97
	S. barley	2.81	1.51	0.14	1.01	0.01	0.14
	S. beans	3.58	1.1	1.28	1.16	0.04	0
	WOSR	5.19	2.19	1.22	1.49	0.29	0
	Fallow	2	2	0	0	0	0
AS	W. wheat	5.59	1.73	0.59	2.23	0.07	0.97
	S. wheat	3.56	0.86	0.30	1.42	0.01	0.97
	S. barley	2.02	0.86	0.05	0.96	0.01	0.14
	S. beans	2.72	0.77	0.98	0.94	0.02	0.00
	WOSR	3.33	1.70	0.19	1.27	0.18	0.00
IS1, no fallow	W. wheat	4.89	1.64	0.47	1.78	0.07	0.92
	S. wheat	2.97	0.82	0.10	1.13	0.01	0.92
	S. barley	1.77	0.82	0.05	0.76	0.01	0.13
	S. beans	2.11	0.73	0.51	0.84	0.02	0.00
	WOSR	2.12	1.47	0.15	0.34	0.17	0.00
IS1 with fallow	W. wheat	4.88	1.64	0.47	1.78	0.07	0.92
	S. wheat	2.97	0.82	0.10	1.13	0.01	0.92
	S. barley	1.77	0.82	0.05	0.76	0.01	0.13
	S. beans	2.11	0.73	0.51	0.84	0.02	0
	WOSR	2.11	1.47	0.15	0.34	0.16	0
	Fallow	1.70	1.7	0	0	0.00	0

*PGR = Plant growth regulator

Table 16. Reduction in Treatment Frequency Index for UK proposed alternative (AS) and innovative (IS1) cropping systems in comparison with the current (CS) cropping system.

								Effect of crop sequence change		Effect of crop sequence plus changed practices	
Rotation no.	**System**	**No. years**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Mean TFI p.a.**	**% change in TFI p.a.**	**Mean TFI p.a.**	**% change in TFI p.a.**
-	Current	3	WW	WW	WOSR			6.2		6.2	
I	AS	4	WW	S Beans	WW	WOSR		5.6	-11	4.3	-31
II	AS	5	WW	S Beans	WW	S Wheat	WOSR	5.3	-14	4.2	-33
II	AS	5	WW	S Beans	WW	S Barley	WOSR	5.0	-20	3.8	-38
III (S)	IS1	5	WW	S Beans	WW	S Wheat	WOSR	5.3	-14	3.4	-45
III (S)	IS1	5	WW	S Beans	WW	S Barley	WOSR	5.0	-19	3.2	-49
III (F)	IS1	5	WW	S Beans	WW	Fallow	WOSR	4.9	-22	3.1	-50
IV (S)	IS1	4	WW	S Beans	S Wheat	WOSR		5.0	-20	3.0	-52
IV (S)	IS1	4	WW	S Beans	S Barley	WOSR		4.6	-26	2.7	-56
IV (F)	IS1	4	WW	S Beans	Fallow	WOSR		4.4	-30	2.7	-57

DEXiPM ANALYSES ON UK AS AND IS1 SYSTEMS

Current System (CS): W. wheat – W. wheat – W. oilseed rape
Alternative sytem (AS): W. wheat – S. beans – W. wheat – W. oilseed rape
Innovative system (IS1): W. wheat – S. beans – W. wheat – Fallow – W. oilseed rape

Context of the analysis
For the DEXiPM comparison of the systems, the farm is assumed to be an arable farm in the east of England with a clay/clay-loam soil type. Leaching risk is high to medium and runoff risk is medium due to the high rainfall in the UK.

Inputs to DEXiPM
The following table presents the choice of DEXiPM input settings used for the comparison of UK systems. There are rather few differences between the inputs of the three systems as reductions in pesticide use depended to a significant extent on the choice of crop sequence. The inputs chosen reflect the current agricultural practices and those that would be acceptable to UK growers in the future to maintain productivity and profit.

Option	Current system	Alternative system	Innovative system	Comment
Leaching risk (soil and climate)	High to medium	High to medium	High to medium	Fixed for comparison
Runoff risk due to context	Medium	Medium	Medium	Fixed for comparison
Field erosion risk due to context	Low	Low	Low	Fixed for comparison
Hydromorphic soil	No	No	No	Fixed for comparison
Potential yield	Very high	Very high	Medium to high	Fixed for comparison
Regional intensification	Not favourable to biodiversity	Not favourable to biodiversity	Not favourable to biodiversity	Assumed that the area is mainly farmland
Availability of uncropped land	Very low	Very low	Low to medium	Intensive agricultural area, fallows and uncropped stubbles introduced
Non-productive areas	Low proportion	Medium proportion	Medium proportion and high connectivity	Intensive agricultural area with landcape management
Average market price	Medium to high	Medium to high	Medium to high	Assuming prices remain stable
Labour hourly wage	High to medium	High to medium	High to medium	The wages in the UK are generally high compared to the rest of EU
Local availability of water for irrigation	Medium	Medium	Medium	Little use of irrigation
Financial security of the farm	Medium	Medium	Medium	Needs to remain the same
Number of crops	Medium to low	Medium to low	Medium to low	See the description of the systems
Proportion of summer, late-harvest crops	Very low	Medium to low	Medium	Currently none, would increase in AS and IS
Crop type	1 type	2 types	3 types	Winter, spring crops and fallow
Crop effect on pollinators	Little favourable	Favourable	Favourable	Benefit of to oilseed rape, increasing with introduction of beans
Additional seed cost of crop species or cultivars	Moderate	Moderate	Moderate	Standard seed prices
Sowing density	Medium	Medium	Medium	Will not be changed significantly unless grass weed problem
Soil cover	High	High	High	In all rotations soil cover is high
TFI of insecticide	Medium	Low	Low	For the CS, actual data were available. Other data are estimated based on expert knowledge
TFI of fungicide	High	Medium	Low	
TFI of herbicide	High	Medium	Medium	
Total Pesticide TFI	High to medium	Medium to low	Medium to low	
Pesticide mobility	High to medium	High to medium	High to medium	Worst case due to sulfonylureas
Pesticide eco-toxicity	Medium to low	Medium to low	Medium to low	Due to the strict approval system
Soil cover at pesticide application	Medium	Medium	Medium	Applications throughout year
Mineral N fertilizer applications	Medium	Medium	Medium	Required to maintain yield
Organic N fertilizer applications	None	None	None	
Organic amendments	None	None	None	
Coverage of crop Nitrogen requirement	Balanced	Balanced	Balanced	Only use as necessary
Mineral P fertilizer applications	Medium	Medium	Medium	Usually with N
P surplus	Low	Low	Low	Only applied as required
Mineral K fertilizer applications	Low	Low	Low	Only applied as required

Total number of treatment operations	8 or more	4-7	4-7	As few as possible with tank mixing
Deep tillage	Less than half	Less than half	Less than half	Due to the benefits on weeds in particular
Inversion tillage	With inversion	With inversion	With inversion	
Superficial tillage in the crop (mechanical weeding)	None	None	1 per year	Only relevant in OSR
Superficial tillage between crops (including false seedbed)	1-3 per year	1-3 per year	1-3 per year	Rather 1 than 3
Irrigation	None	None	None	Plenty of rain in the UK
Risk of water stress	Low	Low	Low	Compared to other parts of Europe it is low
Fuel consumption at harvest	Medium	Medium	Medium	As efficient as possible
Stubble/straw management	Not exported	Not exported	Not exported	. Often it is chopped. Burning not allowed
Capacity of crop sequence to uptake N during the leaching period	Medium to low	Medium to low	Medium to low	
Yield reduction due to system, other than nutrition and pests or weeds	No	Medium	Medium	Due to choice of other species. Spring crops yield less than winter wheat
Habitat management	None	Low increase	Low increase of % non-productive areas and increase of connectivity	Farmers keen to be green
Habitat management quality	Favourable to flora	Favourable to flora	Favourable to flora	
Pest control	High	High	High	All systems will provide the farmer with satisfactory control
Number of hours	Medium to low	Medium to low	Medium to low	AS and IS1 aim to spread workload
Risk of simultaneous operations, due to a limited number of suitable days	Medium	Low	Low	AS and IS1 aim to spread workload
Physical difficulty and disturbance	Medium	Medium	Medium	AS and IS1 aim to spread workload
Heavy metal contamination	None	None	None	Not relevant in these systems
Proportion of gross margin due to main crop	High	High	High	All crops are considered main crops
Risk of pesticide residuals in product	Medium to low	Medium to low	Medium to low	Approval system with limits in the UK
Risk of mycotoxin contamination	Medium to low	Medium to low	Medium to low	
Production risk	Low	Low	Low	Grass weeds the main problem, AS and IS1 provide control phase
Pest pressure	Medium	Medium	Medium	Pests remain, but should get better control
Quantity of rain during late harvest	High to medium	High to medium	High to medium	Impossible to estimate, varies from one year to another
Requirement for agricultural equipment	High	High	High	Standard machinery
Risk of pesticide drift due to material	Medium	Medium	Medium	Sprays still required, even under AS and IS1
Farmer and employees knowledge and skills	High	High	High	UK farmers well educated and efficient
Affiliation to a farm support network	Affiliation to a network corresponding to the strategy	Affiliation to a network corresponding to the strategy	Affiliation to a network corresponding to the strategy	All UK growers use professional advice when making decisions since they cannot afford not to.
Availability of relevant advice for the strategy	High	High	High	
Environmentally based direct subsidies in support of the strategy	High	High	High	Various government-funded schemes in place
Non-environmentally based direct subsidies in support of the strategy	Medium	Medium	Medium	
Access to relevant technologies	Easy	Easy	Possible	Most operations, also in the IS systems can be made with already available knowledge/material
Delivery constraints	None	None	None	Efficient transport network available
Compatibility with technological/aesthetical requirements	*	*	*	
Compatibility with certification requirements	High or no certification requirement	High or no certification requirement	High or no certification requirement	
Valuation or devaluation of price due to crops in the crop sequence	Neutral	Neutral	Neutral	No change in the amount of cash crops
Valuation or devaluation of price due to quality and certification requirements	Neutral	Neutral	Neutral	No change in the amount of cash crops
Reluctance/reservation of the farmer to adopt the strategy	None	*	*	As and IS1 designed to be “acceptable”
Social accessibility of product for consumers	Accessible	Accessible	Accessible	Really only a problem for WOSR
Societal value of landscape	Indifferent	Good	Good	
Acceptability of the strategy by society	Indifferent	Acceptable	Acceptable	Farming perceived to be less environmentally damaging

Analysis and discussion

In Figure 5, the overall sustainability of the three proposed systems for the UK is shown. The results indicate that the overall sustainability remains the same for the Alternative and Innovative systems, compared to the Current system with all three being assessed to give a 'medium' level of overall sustainability. At first sight, this result might appear to indicate that the proposed AS and IS systems had succeeded in maintaining productivity and profitability despite a reduction in the proportion of winter wheat in the rotation and the introduction of lower yielding spring crops, an outcome that would be very acceptable to the agricultural industry. However, more detailed analysis highlights differences between the systems in the ways that the overall level of sustainability was achieved (Figure 6). Whereas the social sustainability of each of the three systems was consistently assessed as 'high', DEXiPM suggested that the environmental sustainability improved from low (CS) to medium (AS & IS) and that this was counterbalanced by a decline in economic sustainability from low (CS & AS) to very low (IS1) (Figures 6 and 7). Thus a reduction in the environmental footprint of the industry appears to have been achieved at the expense of profitability and (probably) productivity, a change that would have important implications for policymakers as well as farmers.

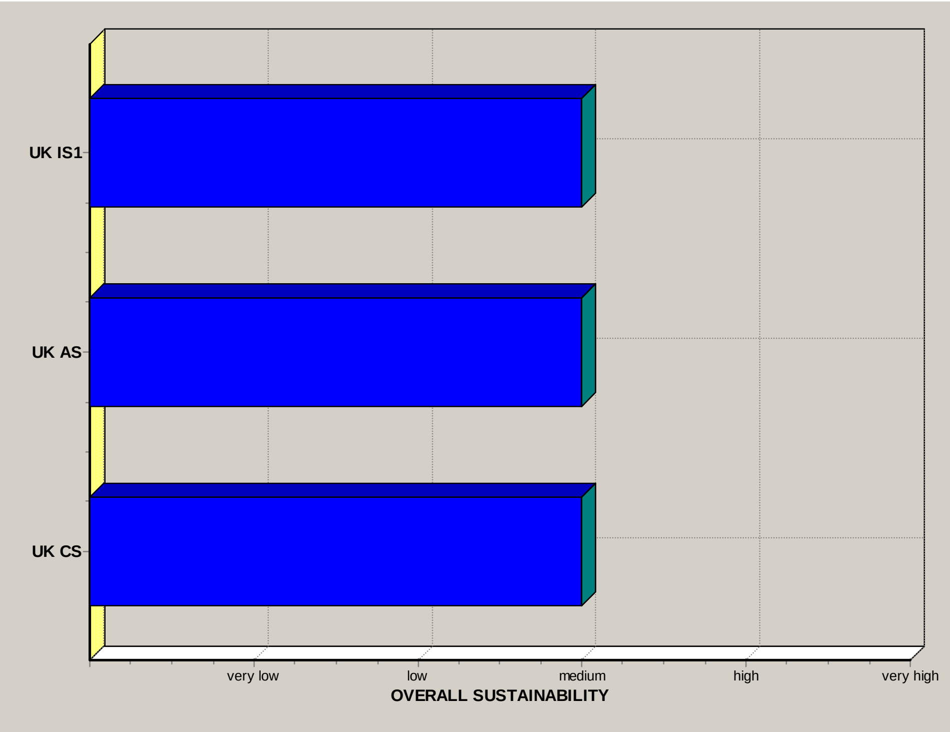


Figure 5. Overall sustainability of the UK Current System (CS) and for the proposed Alternative System (AS) and Innovative System (IS1).

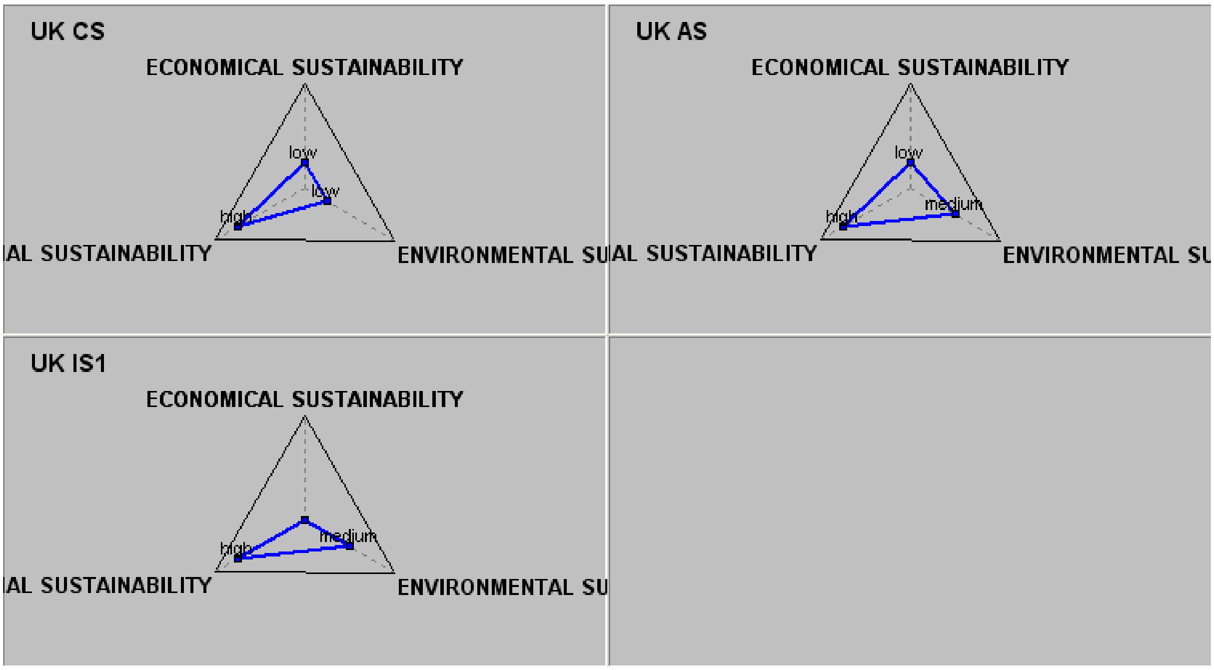


Figure 6. Comparison of economical, social and environmental sustainability of the UK Current System (CS) and the proposed Alternative System (AS) and Innovative System (IS1).

Economic sustainability

A reduction in gross margin was detected by DEXiPM for IS1 (Figure 7) but probably also occurred to some extent in the AS system. This reduction in profitability must be concomitant with the introduction of less profitable and/or less productive spring crops and with the use of a fallow in the IS1, as there was not an increase in costs (Figure 8). Such a reduction would be of great concern to growers and advisors, but it should be noted that the use of an IS1 rotation with a fallow is proposed only for sites where there are significant problems with herbicide-resistant grass weeds, in which case the loss would be significantly countered by the advantages that this IS1 system brings for grass weed management. An IS1 system with a fallow has been chosen for DEXiPM analysis here as an example that is very different from UK CS but other UK IS1 options without fallow have been suggested for sites without severe herbicide-resistance problems (see ‘Proposals of AS and IS1 for each country’ above).

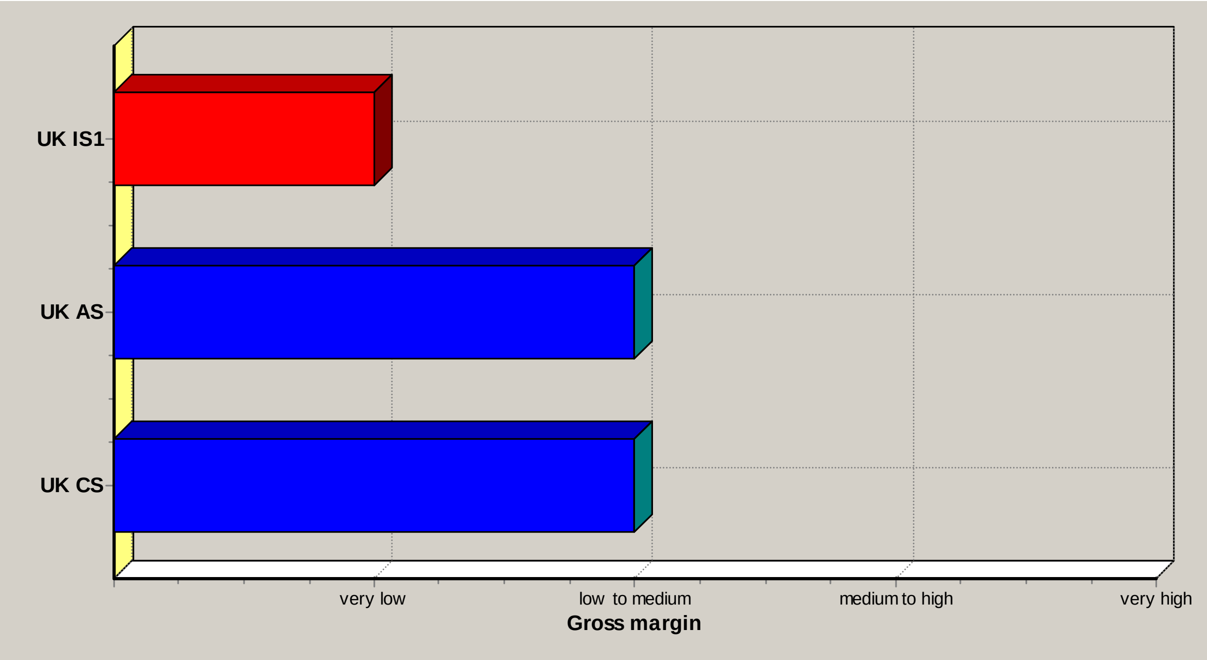


Figure 7. Comparison of assessment of gross margin of the UK Current System (CS) and the proposed Alternative System (AS) and Innovative System (IS1).

Analysis of some production costs shows that the proposed AS and IS1 systems carried similar costs to each other but both achieved reductions in fuel and pesticide costs compared to CS (Figure 8). The cost of pesticide, rated as high under the CS, was reduced to medium in the AS and IS1 systems due to the reduced use of all pesticides (31% and 50% TFI reductions for AS and IS1, respectively). The biggest TFI savings were achieved in herbicides and fungicides. The cost of fertilizers remained high in order to maintain yield under all three systems. The assessment for the cost of fuel decreased from ‘high to medium’ for the CS to ‘medium to low’ for both the AS and IS1, presumably because of the lower number of passes through the crop/system as pesticide usage levels were reduced. The cost of seeds remained constant. Unlike the Danish system, irrigation costs are not an issue in the UK and this was not included in the analysis.

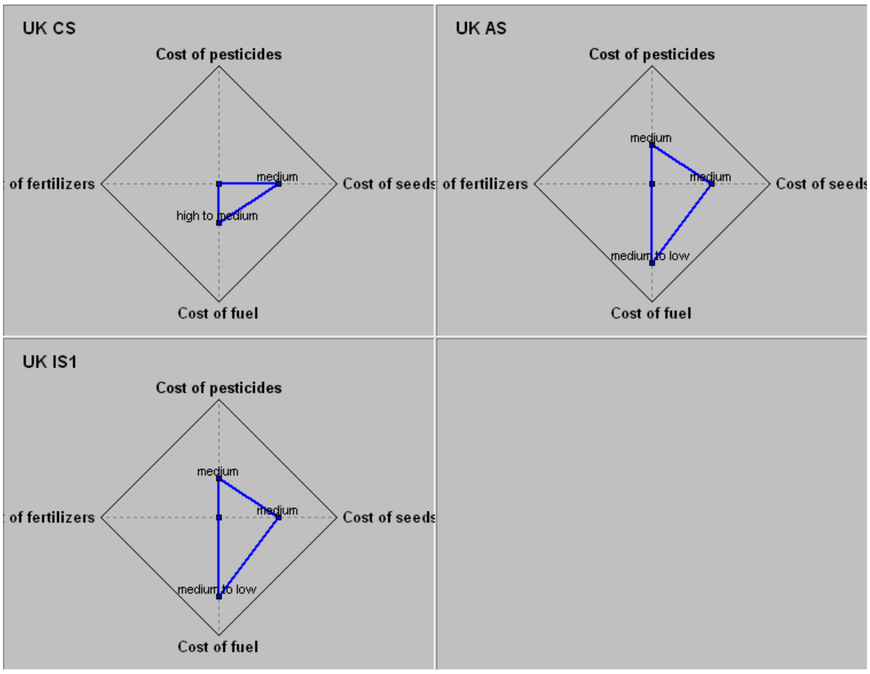


Figure 8. Comparison of costs between the UK Current System (CS) and the proposed Alternative System (AS) and Innovative System (IS1).

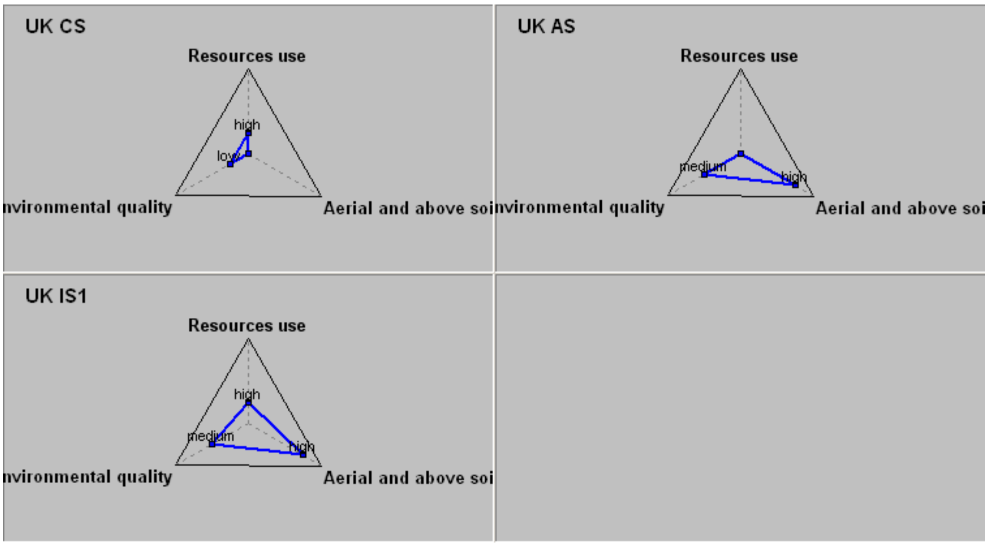


Figure 9. Comparison of three parameters (Resources use, Environmental quality and Aerial and above soil biodiversity) relating to environmental sustainability between the UK Current System (CS) and the proposed Alternative System (AS) and Innovative System (IS1).

Environmental sustainability

The DEXiPM assessment suggested that both UK AS and UK IS1 systems achieved some environmental benefits compared to the CS. The environmental quality rating improved from ‘low’ for the CS to ‘medium’ for both the AS and IS1 systems, presumably because of the reduction in pesticide use and associated reduction in sprayer passes through the crop/system. Further analysis with the DEXiPM tool suggests that for the CS and two proposed AS and IS1 systems, water quality and soil quality remain the same (both rated ‘low to medium’) but that reduced air emissions (falling from ‘High to medium’ to ‘Medium to low’) account for the improved environmental quality. Both the AS and IS1 reduced direct CO_2 emmissions and the reduced TFI associated with each system also reduced volatization of pesticides.

DEXiPM suggested that the largest difference between the three UK systems in terms of environmental sustainability was achieved in ‘Aerial and above ground biodiversity’, rated as ‘very low’ under CS but ‘high’ for both the AS and IS1 systems. Figure 10 indicates how the proposed systems were assessed to be beneficial to flora, fauna and weeds (presumably diversity of the seed bank). All three parameters were rated ‘very low’ under CS, but all increased with TFI reductions and changes in practices associated with the AS system and further improvements under the proposed IS1 system.

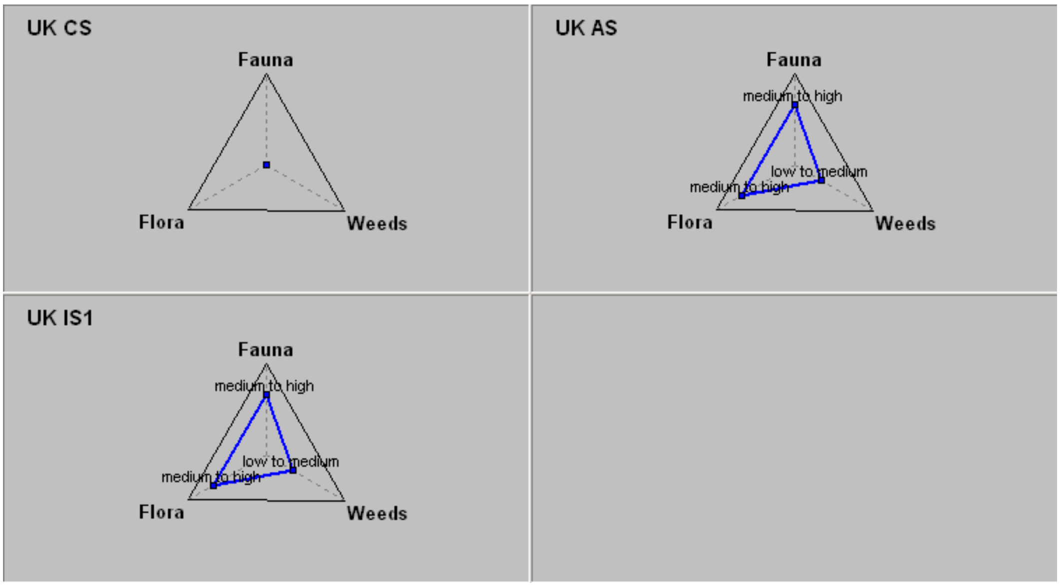


Figure 10. Comparison of three parameters (Fauna, Flora and Weeds) relating to Environmental Quality between the UK Current System (CS) and the proposed Alternative System (AS) and Innovative System (IS1).

Social sustainability
A high rating for ‘social sustainability’ was maintained in all three systems (Figure 6). The need for farmers to spread the workload is an important driver of rotations and the diversification into spring/other crops in UK AS & IS1 systems is reflected in DEXiPM’s assessment of ‘operational difficulties’ as ‘medium to low’ (CS) and ‘very low’ (AS and IS1). Although ‘work hardness’ was rated as ‘medium to low’ for all three systems, the medium to low ‘complexity’ rating for current practices was reduced to very low for both the AS and IS1 proposed systems. The introduction of spring crops and possibly a fallow (suggested by growers and advisors) was a key factor in terms of ‘farm manageability’.

Conclusion
A major concern to UK growers and their advisors aired during consultation in advance of this exercise was the maintenance of current levels of production and profit. With this in mind, AS and IS1 systems were proposed that represented relatively modest changes to the current cropping system rather than radical redesigns. An important aim of the proposed systems was to allow management of grass weed problems and to introduce genetically different crops to help combat risk of all pests. The proposed crop sequences were also designed to spread the workload on the farm. Many of the differences between the systems were subtle or were variations on current practices and this, as might be expected, was often

reflected in the ratings given by DEXiPM to the three systems. Environmental benefits were achieved, associated with pesticide reductions, reduced fuel costs and emissions, spring cropping and fallows, but they were accompanied by some compromise to the economic sustainability of the IS1 system. Social sustainability was maintained.

As a framework for structuring comparison of the sustainability and performance of the CS, AS and IS1 systems, DEXiPM analysis provided a synthesis of expert assessments relating to the environmental and economic sustainability of the proposed sytems. The results obtained were consistent with expectation based on that expert opinion. As such, DEXiPM assessments were a test of the thinking behind the proposals for the three systems. While DEXiPM cannot replace a full and objective socio-economic and environmental impact assessment, it is a worthwhile preliminary to such an analysis.

France

One AS and two IS1 are proposed, corresponding to three current situations with different context and pre-requisite. The AS and IS1 systems are all presented in details in Appendix A.

Bassin Parisien

CONTEXT

- **Site:** France, *Bassin Parisien*
- **Soil and climate:** loamy, deep soils (no risk of water stress, medium leaching risk, medium erosion risk), degraded oceanic climate
- **Regional context:** intensive, low proportion of non-productive area
- **Specificity of the farm where the system is proposed:** industrial crops

CURRENT SYSTEM

Crop sequence: sugarbeet-winter wheat-winter oilseed rape-winter wheat
Crop protection strategy: pesticides (TFI 7.2 year^{-1}, Table 17), genetic
Main pest risk: spring weeds in sugar beet, autumn weeds in winter crops; aerial diseases on wheat
Expected yield given the context: high (Table 17).
Other crop management specificity:

- Superficial tillage: no mechanical weeding and no false seedbed
- No intermediate crop
- Deep tillage: higher frequency in comparison with IS
- Sowing density: high (lower in IS)
- Mineral fertilizers: high for N (lower in IS)

Table 17. Estimated TFI of current systems (ha^{-1} $year^{-1}$) (source: Ecophyto R&D report Guichard *et al*. 2009) and estimated potential yields of crop (Source: Persyst *Champagne* and *Poitou Charentes,* Guichard, 2008).

	Bassin Parisien	***Poitou Charentes***	***Bourgogne***
TFI Herbicide	2.4	2.1	2.2
TFI Fungicide	2.1	1.5	2.1
TFI Insecticide	1.9	1.6	1.7
Total TFI	**7.2**	**5.8**	**7.1**
Yields	WWh: 7.5-9.5 t^{-1} ha^{-1} WOSR: 3.3-4.5 t^{-1} ha^{-1} Sugarbeet: 80-105 t^{-1} ha^{-1}	5.3-6.9 t^{-1} ha^{-1} WWh 2.5-3.4 t^{-1} ha^{-1} WOSR 5.8-7.4 t^{-1} ha^{-1} WB	5.3-6.9 t^{-1} ha^{-1} WWh 2.5-3.4 t^{-1} ha^{-1} WOSR 5.8-7.4 t^{-1} ha^{-1} WB

INNOVATIVE SYSTEM

Proposed crop sequence for IS prototype:

sugarbeet-winter wheat-(mustard)-hemp-winter wheat-winter oilseed rape-winter wheat-(mustard)

Main crop protection principles:

- Extending and diversifying crop rotation: competitive crops are added (weeds), the frequency of a given crop is lowered (disease)
- Diversifying sowing periods by shifting sowing dates (early/late sowing dates): impact on weeds (allow false seedbed on wheat sown later, competitiveness of WOSR sown earlier is increased against weeds), on disease (e.g. WOSR sown earlier is less susceptible to phoma) and on insects (e.g. autumn aphids on wheat sown later, winter flee beetle (*psylliodes chrysocephala*), *tenthredinidae* and slugs on WOSR sown early)
- Superficial tillage: mechanical weeding and false seedbed.
- Systematic intermediate catch crop when spring crops: competitiveness against Autumn weeds.
- Odd number of deep tillage between two successive cereals: the seedbank is buried when the cereal is sown.
- Use of resistant cultivars.
- WOSR cultivar mixture with 10% early and taller WOSR cultivars (the hypothesis is that pollen beetles are attracted by this cultivar, the 90% plants remaining might be less attacked; Valantin-Morison *et al.*, 2006a)
- Straws chopped and buried: slugs
- Decrease sowing density, N fertilizer amounts

Possible positive impact:

- Intermediate crop: less N on crops, reduction of NO3 leaching
- Straws buried: increase soil organic matter content (long term effect)

Possible negative impacts:

- Mechanical weeding-superficial tillage between crops: energy and time cost
- Late sowing (cereals): risk of unsuitable sowing conditions, reduction of yield
- Extending rotations: lower frequency of cash crops, delivery constraints for some crops (hemp)
- Intermediate crop: risk to increase slugs
- No growth regulator: lodging problems (but N fertilization is decreased)
- Introduction of hemp: risk of broom rape and sclerotinia

Poitou Charentes

CONTEXT

- **Site:** France, *Poitou Charentes*
- **Soil and climate:** limestone plateau, shallow soils (risk of water stress, high leaching risk, low erosion risk), oceanic climate
- **Regional context:** intensive
- **Specificity of the farm where the system is proposed:** farm area > 100ha: it is not always possible to delay the winter wheat sowing date (risk of simultaneous operations), availability of tools for mechanical weeding, no irrigation.

CURRENT SYSTEM

Crop sequence: winter oilseed rape-winter wheat-winter barley
Crop protection strategy: pesticides (TFI=5.8 year^{-1}, Table 17), genetic
Main pest risk: weeds: *Galium aparine*, wild oats (*Avena fatua*), *Geranium* (cereals), *Ammi majus* (sunflower); insects: stem weevil, pollen beetle (WOSR), aphids (spring: WOSR, autumn: WWh); diseases: septoria on cereals, sclerotinia on WOSR
Expected yield given the context: medium to high (Table 17)
Detailed crop management specificity:

- Superficial tillage: no mechanical weeding and no false seedbed
- No intermediate crop
- Deep tillage: higher frequency in comparison with AS
- Sowing density: high (lower in AS)
- Mineral fertilizers: high for N (lower in AS)

ADVANCED SYSTEM

Proposed crop sequence for AS prototype:
winter oilseed rape-winter wheat-winter barley-(intermediate legumes)-sunflower-winter wheat
Main crop protection principles:

- Diversifying crop sequence and sowing periods by introducing spring crops and shifting sowing dates: non-specialized weed flora
- Systematic intermediate catch crop when spring crops: autumn weeds
- Mechanical weeding and false seedbed, deep tillage when necessary
- Diversifying sowing periods by shifting wheat sowing dates when it is possible: impact on weeds (allow false seedbed on wheat sown later) and on insects (e.g. autumn aphids). The delay in wheat sowing date is not systematic.
- Sowing density: double row spacing for WOSR (mechanical weeding)
- Use of resistant cultivars, wheat cultivar mixture
- WOSR cultivar mixture with 10% early and taller WOSR cultivars (the hypothesis is that pollen beetles are attracted by this cultivar, the 90% plants remaining might be less attacked; Valantin-Morison *et al*., 2006a)
- Straws chopped and buried: slugs
- Decrease sowing density, N fertilizer amounts

Possible positive impact:

- Intermediate crop: less N application on crops, reduction of NO3 leaching
- Straws buried: increase soil organic matter content (long-term effect)

Possible negative impacts:

- Mechanical weeding-superficial tillage between crops: energy and time cost
- Late sowing (cereals): risk of unsuitable sowing conditions, reduction of yield

- Extending rotations: lower frequency of cash crops
- Intermediate crop: risk to increase slugs
- No growth regulator: lodging problems (but N fertilization is decreased)
- Wheat cultivar mixtures: possible problems to sell the production in France

Bourgogne

CONTEXT
- **Site:** France, *Bourgogne*
- **Soil and climate:** limestone plateau, shallow soils (low hydric deficiency, high leaching risk, low erosion risk)
- **Regional context:** intensive, cattle livestock in surrounding farms in the region
- **Specificity of the farm where the system is proposed:** minimum tillage, availability of tools for mechanical weeding, no irrigation.

CURRENT SYSTEM
Crop sequence: winter oilseed rape-winter wheat-winter barley
Crop protection strategy: pesticides (TFI=7.1 year^{-1}, Table 17), genetic
Main pest risk: autumn emergence weeds (all crops), weevil, pollen beetle (WOSR), aphids (WW)
Expected yield given the context: medium to high (Table 17)
Detailed crop management specificity:
- Superficial tillage: no mechanical weeding and no false seedbed
- No intermediate crop
- Deep tillage: no deep tillage (one mouldboard ploughing after alfalfa in the IS)
- Sowing density: high (lower in IS)
- Mineral fertilizers: high for N (lower in IS)

INNOVATIVE SYSTEM
Proposed crop sequence for IS prototype:
winter oilseed rape-winter wheat-spring barley-alfalfa-alfalfa-winter wheat-(mustard)-sunflower-triticale
Main crop protection principles:
- Diversifying crop sequence and sowing periods by introducing spring crops and shifting sowing dates: non-specialized weed flora (enhanced for the IS in comparison with the AS)
- Increase the frequency of crops with high competitiveness against weeds (including alfalfa perennial crop)
- Diversifying sowing periods by shifting sowing dates (early/late sowing dates): impact on weeds (allow false seedbed on wheat sown later, competitiveness of WOSR sown earlier is increased, early sowing date for spring barley to increase competitiveness), on disease (e.g. WOSR sown earlier is less susceptible to phoma), on insects (e.g. autumn aphids on wheat sown later, winter flee beetle (*psylliodes chrysocephala*), *tenthredinidae* and slugs on WOSR sown early). Systematic late sowing date for winter wheat
- Landscape management: if possible, small fields (<10 ha), settlement of hedges or other non-productive areas, flowering strips for pollinators, refuges for natural enemies, turnip rape (*Brassica rapa*) on WOSR margins (to trap pollen beetle; Valantin-Morison *et al.*, 2006b)

- Mechanical weeding and false seedbed, deep tillage only after alfalfa (favour natural enemies)
- Use of resistant cultivars
- WOSR cultivar mixture with 10% early and taller WOSR cultivars (the hypothesis is that pollen beetles are attracted by this cultivar, the 90% plants remaining might be less attacked; Valantin-Morison *et al.*, 2006a)
- Straws exported: slugs
- Use of Contans® each year (biological control) against sclerotinia
- Decrease sowing density, N fertilizer amounts

Possible positive impact:

- Intermediate crop (not systematic as before): less N application on crops, reduction of NO3 leaching
- limitation of green house gases emission (less N applications)
- Landscape management: good perception by society
- Biodiversity (pollinators) : alfalfa, sunflower

Possible negative impacts:

- Mechanical weeding-superficial tillage between crops: energy and time cost
- Late sowing (cereals): risk of unsuitable sowing conditions, reduction of yield
- Extending rotations: lower frequency of cash crops, delivery constraints for some crops (alfalfa, triticale)
- Intermediate crop: risk to increase slugs
- No growth regulator: lodging problems (but N fertilization is decreased)
- Straws exported: limit soil organic matter content
- Biological control (Contans®): cost
- Landscape management: loss of productive area, crop mosaic reorganization

The context and current system in *Poitou Charentes* and *Bourgogne* are similar. It is therefore possible to compare the evolution between AS and IS based on the same CS. Main differences are the landscape management for the IS, the diversification of the crop sequence that is enhanced in the IS, the systematization delaying of sowing dates for wheat in the IS, the use of a biological control method in the IS, and the limitation of deep tillage (also linked with the specificity of the farm). These systems will be assessed together in the following part.

<u>Assessment of systems</u>

1/ Pesticides TFI[1]

TFI values for French current systems correspond to those described in the Ecophyto R&D report (Ecophyto R&D report Guichard *et al.*, 2009) for the intensive cropping systems. A half-dose glyphosate treatment was applied between crops 2 years out of 3 for the WOSR-WWh-WB crop sequence (before wheat and barley) and 2 years out of 4 for the Sb-WWh-WOSR-WWh crop sequence (before sugar beet and wheat following WOSR).

---

[1] Average pesticide Treatment Frequency Index of commercial products (and not active ingredient) across all crops in the cropping sequence, for fungicides, insecticides, herbicides, molluscicides, growth regulators and all other products used

$TFI = \frac{1}{n}\sum_{t=1}^{t=T}\frac{D_t}{DAp_t}$ with n: number of years in the crop sequence, T: total number of pesticide treatments, D: applied dose in commercial product, DAp: approved/registered dose for the commercial product.

Concerning the AS and IS systems, TFI were calculated according to the detailed description of systems (in appendices). Most treatments were suppressed thanks to the use of alternative control methods (adaptation of sowing dates, use of resistant cultivars landscape management, etc.). Those methods were supposed to be efficient and estimations were quite optimistic. When treatments were maintained, TFI were calculated based on the estimation of the frequency of attacks of more problematic pests (regional data, Aubertot *et al.*, 2005). For example, it was estimated that the frequency of aphid attacks in autumn on the second wheat of the AS in *Poitou Charentes* was three years out of five, leading to a TFI of 0.6 on the crop for the corresponding insecticide. Similarly for the slugs on winter oilseed rape in the IS in *Bassin Parisien*, the frequency of attack was estimated at 1 year out of five, leading to a TFI of 0.2 on the crop for the corresponding molluscicide. When herbicides were applied on row, the TFI was estimated at 0.5 instead of 1. More generally, pesticides were applied at lower dose than in current systems (except for insecticides), where they were commonly applied at full dose.

Table 18. Calculated TFI (ha^{-1} $year^{-1}$) for the three current crop sequences and the corresponding AS and IS. WOSR: Winter Oilseed Rape, WWh: Winter Wheat, WB: Winter Barley, SB: Spring Barley, Sb: Sugarbeet, Sf: Sunflower, Tr: Triticale, Al: Alfalfa, H: Hemp.

Region	***Bassin Parisien***		***Poitou Charentes***		***Bourgogne***	
System	**CS**	**IS**	**CS**	**AS**	**CS**	**IS**
Crop sequence	Sb-WWh-WOSR-WWh	(Mustard)-Sb-WWh-(mustard)-H- WWh - WOSR-WW	WOSR-WWh-WB	WOSR-WWh-WB-(intermediate legumes)-Sf-WWh	WOSR-WWh-WB	WOSR-WWh-SB-Al-Al-WWh -(mustard)-Sf-Tr
TFI Herbicide	2.4	0.8	2.1	0.7	2.2	0.2
TFI Fungicide	2.1	0.7	1.5	0.8	2.1	0
TFI Insecticide	1.9	0.4	1.6	0.6	1.7	0.2
Total TFI	**7.2**	**1.9**	**5.8**	**2.2**	**7.1**	**0.4**

Based on the hypothesis for TFI calculation, the TFI of AS and IS were significantly reduced in comparison with TFI of current systems (Table 18).

2/Multi-criteria assessment with DEXiPM

A detailed description of DEXiPM is available in the deliverable DR 2.14. Estimations of basic attributes for the assessment are based on the detailed description of cropping systems in appendices.

Assessment of current, advanced and innovative systems were performed using DEXiPM. These assessments allow a first view of the sustainability of systems proposed, but were also a way to discuss the reliability of the model, which is still under development.

Differences between systems are not high for the overall sustainability (Figure 11). Although both innovative systems proposed present a higher overall sustainability, the advanced system does not seem to improve the overall sustainability. These results are due to the fact that sustainability of cropping systems does not only depend on TFI but also on other aspects that are taken into account in the DEXiPM tool, such as nitrate leaching, air emissions, energy consumption for the environmental part, costs of all inputs for the economical part, etc. It points out the importance of the multi-criteria assessment of systems. However, these results are also partly due to a lack of sensitivity of the upper attributes of DEXiPM to modifications of systems (basic attributes, such as TFI, fertilizers, tillage, etc.). This is the reason why we present results obtained with the other attributes within the tree.

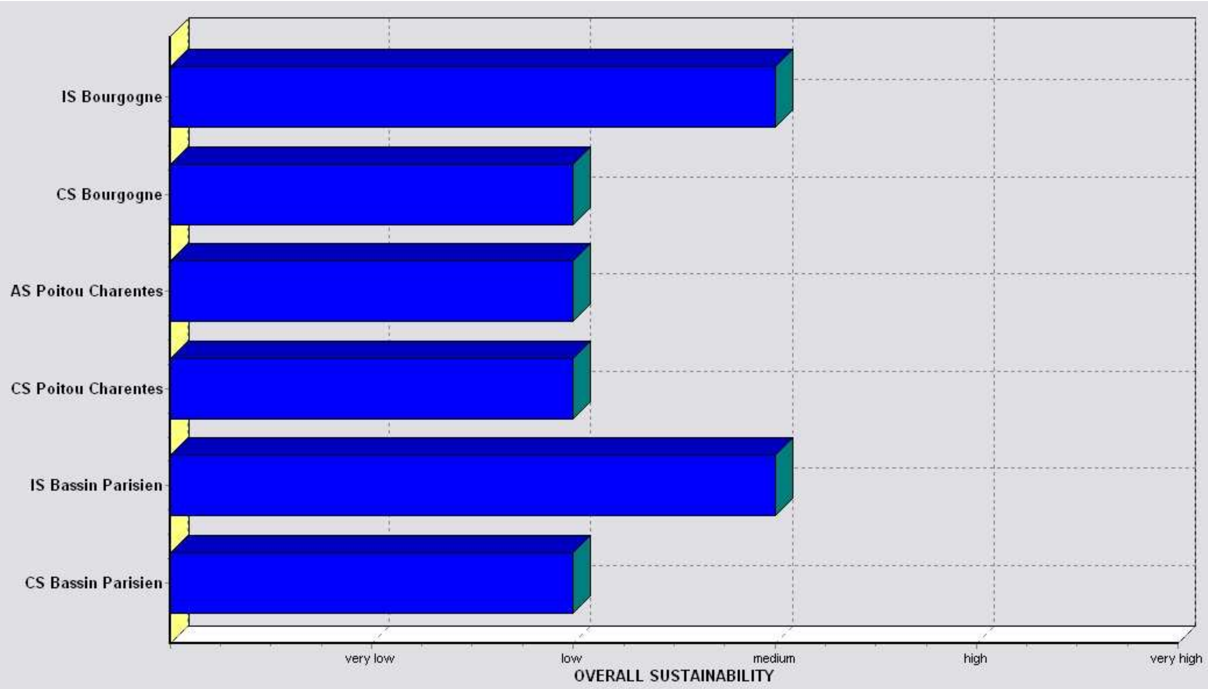


Figure 11. Estimation of the overall sustainability of the three current systems (CS) described in three French regions (*Bassin Parisien*, *Poitou Charentes* and *Bourgogne*) and the corresponding advanced and innovative systems (AS, IS).

Even if current systems are described in two different regions, they are more or less the same (same crop sequence, similar crop management, same pedo-climatic context). We therefore present the results of AS for *Poitou Charentes* and IS for *Bourgogne* in parallel, to be able to compare the evolution between CS, AS and IS. The results for CS and IS in *Bassin Parisien*, corresponding to a different context, are presented separately.

Bassin Parisien

The overall sustainability in DEXiPM takes into account the economical, environmental and social sustainability. Whereas the economical sustainability remains the same between CS and IS (Figure 12), the environmental sustainability is improved by one class (from very low to low) as well as the social sustainability (from medium to high), explaining the difference in the overall sustainability (from low to medium).

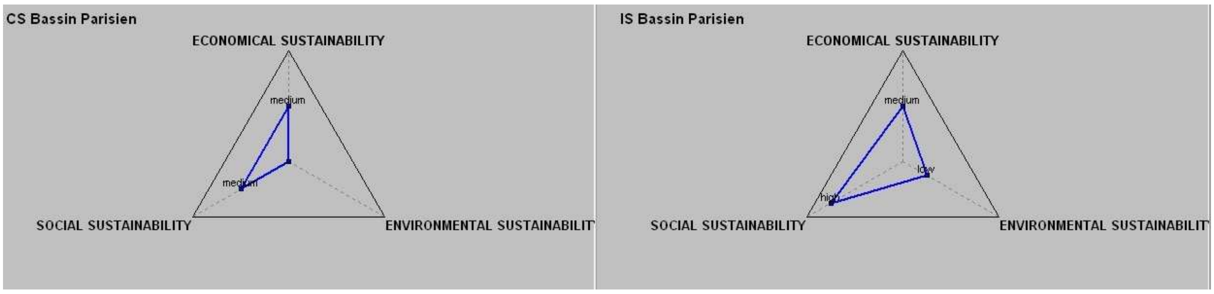


Figure 12. Estimation of the environmental, economical and social sustainability of the current system (CS) and the corresponding innovative systems (IS) described in the French region *Bassin Parisien.*

All the attributes of the environmental sustainability, environmental quality (water, soil and air), aerial and above soil biodiversity (fauna and flora) and resource use (water, land, energy and non-renewable fertilizers) are very low in the current system (Figure 13). The innovative system allows the improvement of the environmental quality by two classes (from very low to medium), mainly because of the lower amount of pesticides but also of nitrogen fertilizer (lower nitrate leaching and nitrous oxide N_2O emissions risk). The resource use is also improved because of a lower energy use due to a lower amount of nitrogen and thus of indirect energy consumption in the IS. Finally, the aerial and above soil biodiversity is better. Moreover, in the IS, the weed diversity is improved because of the diversification of the crop sequence and of the lower use of herbicides, but the weed abundance is the same as in the CS. It can be concluded that alternative methods to control weeds are efficient to decrease weed abundance. The fauna diversity (soil natural enemies, aerial natural enemies, pollinators) is also improved, particularly aerial natural enemies because of a lower use of pesticides and the improvement of flora diversity. Even if the environmental sustainability differs by one class (in comparison with the CS), the analysis of attributes within the tree shows that the IS significantly improve the environmental sustainability. These weak differences between the two systems despite the large modifications of the cropping systems are due to the low sensitivity of the upper attributes of DEXiPM

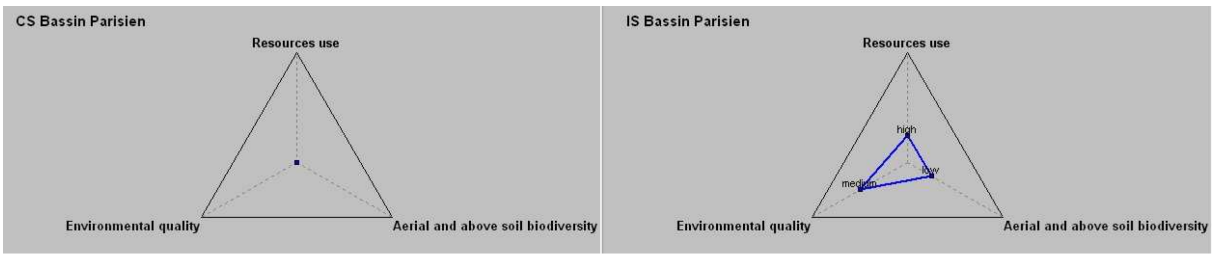


Figure 13. Estimation of the environmental sustainability of the current system (CS) and the corresponding innovative systems (IS) described in the French region *Bassin Parisien*.

The estimation of the gross margin remains the same between both systems (Figure 14), despite a lower yield for the IS (from high for the CS to medium for the IS) leading to a lower production value (from medium to high for the CS to low to medium for the IS). However, this is compensated by a lower production cost for the IS (from high to medium for the CS to medium to low for the IS), mainly because of a lower cost of pesticide and nitrogen. The IS proposed for *Bassin Parisien* does not seem to be altered in terms of economical sustainability.

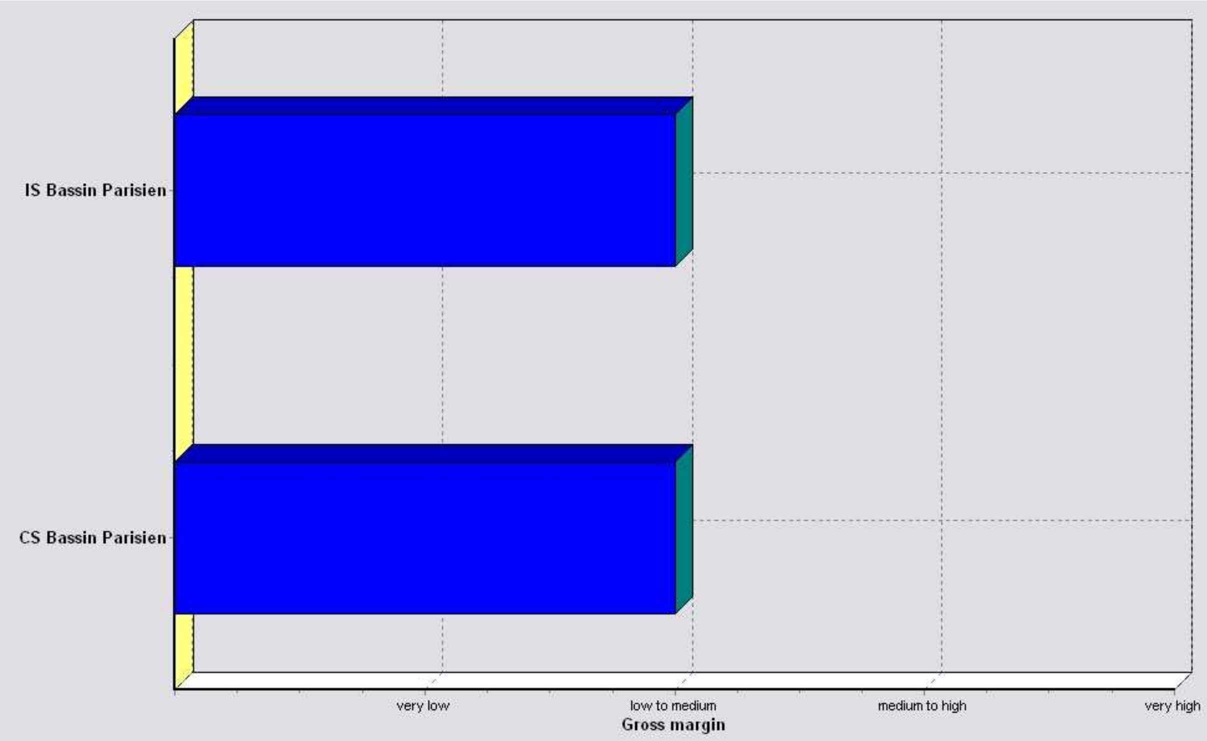


Figure 14. Estimation of the gross margin of the current system (CS) and the corresponding innovative systems (IS) described in the French region *Bassin Parisien*.

The social sustainability of the IS is improved, only because of an improvement of the ‘interaction with society’ attribute, characterized by the contribution to employment (the number of required hours of work for the IS is higher than for the CS) and by the acceptability of the system by society (also better in the IS). Despite small differences, the likelihood of adoption of the IS by farmers remains unchanged. However, it could be considered as lower for the IS. This part of the tree should be modified to reflect this. The operational difficulties linked with the IS increase in comparison with the CS: from very low for the CS to high to medium for the IS. It is due for example to a higher number of superficial tillage operation and risk of simultaneous operations. This was compensated by a lower workers’ health risk due to pesticides (from very high for the CS to low for the IS).

Poitou Charentes and *Bourgogne*

Because of only small differences in the description of current systems, and their similar soils the environmental, economical and social sustainability of *Poitou Charentes* and *Bourgogne*, are similar for both CS (Figure 15). The AS allows an improvement of the social sustainability but leads to a decrease of the economical sustainability. Despite the significant decrease of the TFI, the environmental sustainability was the same between CS and AS, because other practices impacting on the environment such as tillage, fertilizers, etc. were similar. On the contrary, the IS lead to a better environmental and social sustainability, while the economical sustainability remains the same.

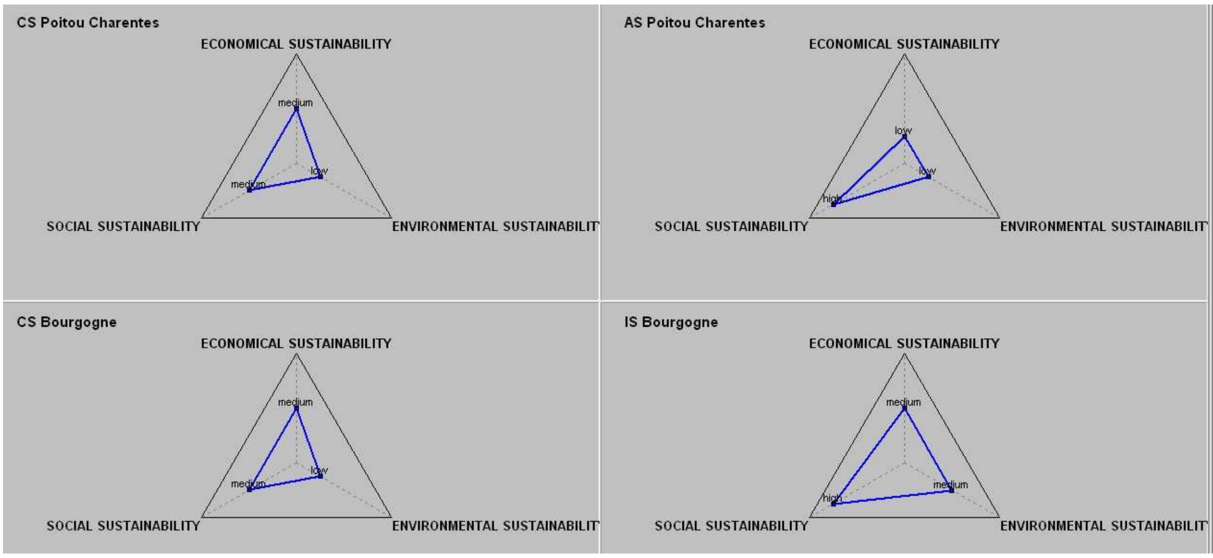


Figure 15. Estimation of the environmental, economical and social sustainability of the current system (CS) and the corresponding advanced and innovative systems (AS and IS) described in the French regions *Poitou Charentes* and *Bourgogne*.

Again, the CS in both regions are similar, except that the aerial biodiversity in the CS in *Bourgogne* is lower compared to the CS in *Poitou Charentes* because of a higher use of fungicide, impacting on aerial natural enemies and pollinators. The resource use was the same between CS, AS and IS (Figure 16), because there are few problems of water in both regions, the same amount of non-renewable fertilizers (P and K) are used in CS, AS and IS, the land use remains high to medium in both systems (because of a low availability in uncropped land in both regions), and only the indirect energy consumption is modified because of a lower amount of nitrogen fertilizer. The pesticide amount is significantly lower in AS and IS but the weight attributed to pesticide manufacturing compared to fertilizer manufacturing is very low.

Only the environmental quality is improved in the AS in comparison with the CS because of a better water quality (from low to medium for the CS to medium to high for the AS) and a lower air emission (from high to medium for the CS to medium to low for the AS), due to a decrease of pesticides and nitrogen fertilizers). Small differences are noticed in the flora diversity, but these differences are too small to appear on the aerial biodiversity.

The IS lead to an improvement of both environmental quality and aerial and above soil biodiversity. As for the AS, the environmental quality was improved mainly because of the decrease of nitrogen fertilizers and pesticides, and no fundamental differences occurred between AS and IS. In this part of the tree, the model does not seem to reflect the very high decrease of TFI between CS and IS in *Bourgogne* (from 7.1 to 0.4) compared to the decrease between CS and AS in *Poitou Charentes* (from 5.8 to 2.2), which is questionable, as the model should be more sensitive to TFI differences. This very high decrease of TFI as well as the diversification of crop sequence and the landscape management implies a high improvement of the aerial biodiversity (from very low for the CS to high for the IS).

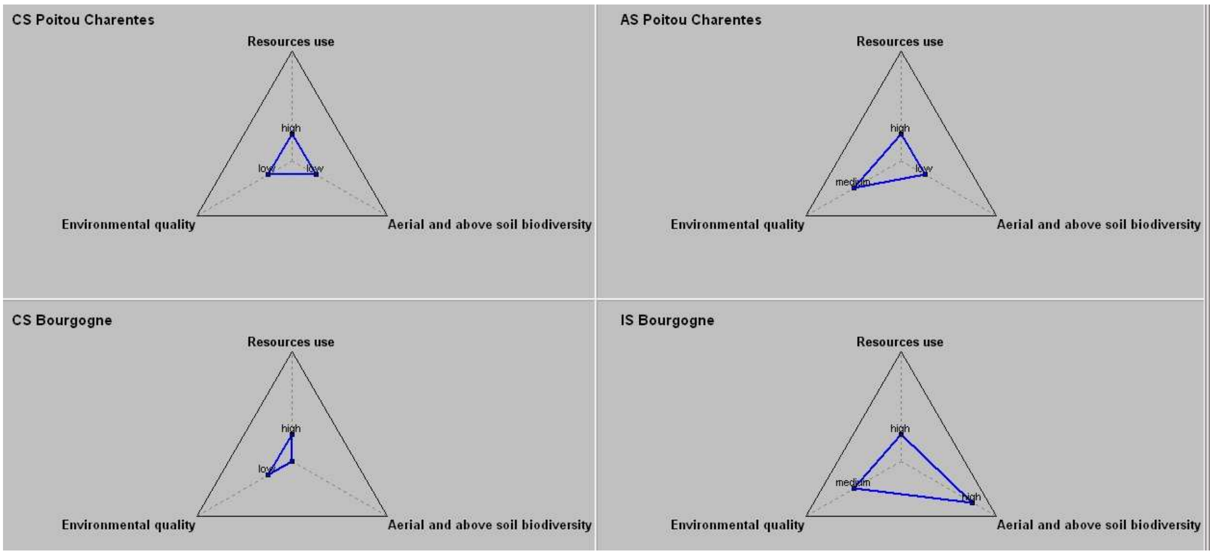


Figure 16. Estimation of the environmental sustainability of the current system (CS) and the corresponding advanced and innovative systems (AS and IS) described in the French regions *Poitou Charentes* and *Bourgogne*.

The gross margin decreases for both AS and IS in comparison with CS (Figure 17). It was due to the fact that the decrease in the production value was higher compared to the previous *Bassin Parisien* IS: very low for AS *Poitou Charentes* and IS *Bourgogne* compared to medium to high for the corresponding CS, and low to medium for the IS *Bassin Parisien* compared to medium to high for the corresponding CS. This decrease was therefore not compensated by the one class decrease of production cost occurring for the IS but not for the AS. This higher decrease in production value is due to the fact that in addition to a decrease in the yield (from medium for the CS to low for the AS and IS), the selling price decreased also because of the cultivar mixture in wheat used in the AS, and because of alfalfa. Indeed in France, it is not always possible to sell cultivar mixture and even if *Bourgogne* is a region with cattle livestock where it should be possible to sell alfalfa, the reluctance of some European partners to the introduction of alfalfa in systems lead to the choice of a penalty in the selling price associated with this crop). The economical viability is the same for CS and IS, leading to the same economical sustainability. On the contrary, the economical viability decreased between CS and AS, mainly because the pesticide dependency remains high in the AS in comparison with the IS. The analysis of the results of the economical sustainability should be analyzed in detail by experts of this discipline. However, it points out that, in some cases, the reduction of pesticides and nitrogen lead to reducing the economic viability of the systems even if many important modifications of cropping systems have been done.

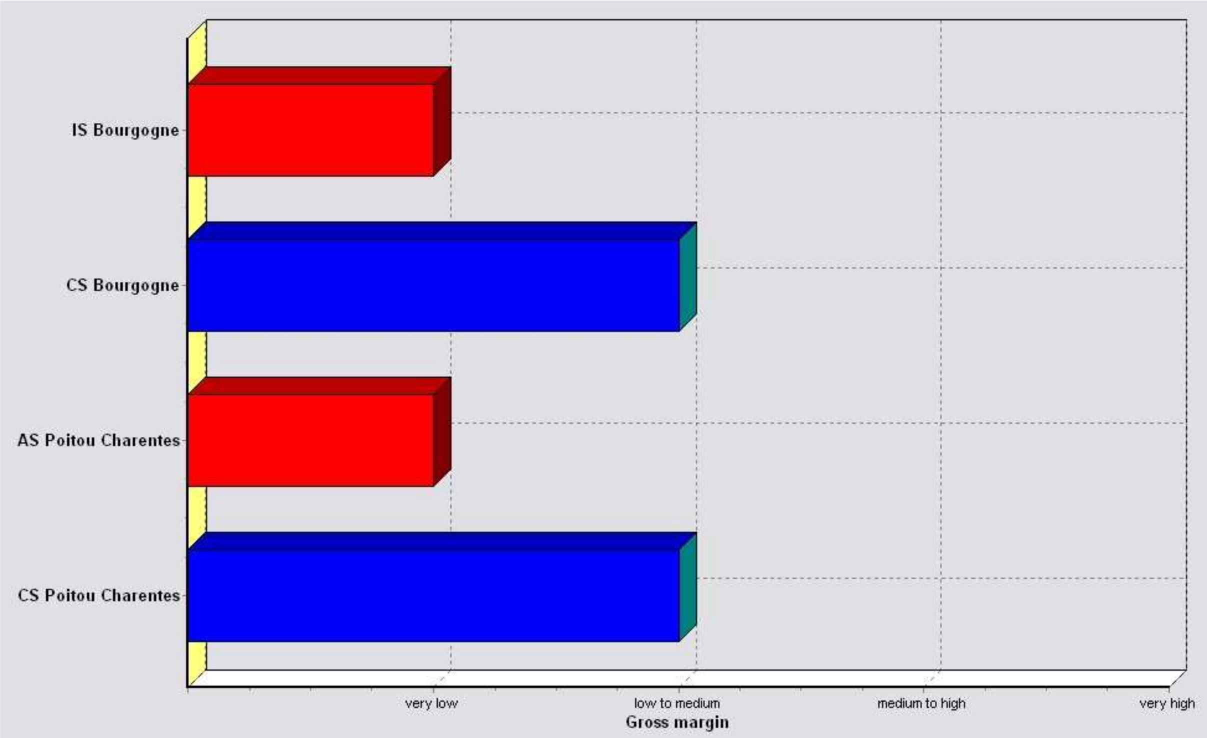


Figure 17. Estimation of the gross margin of the current system (CS) and the corresponding advanced and innovative systems (AS and IS) described in the French regions *Poitou Charentes* and *Bourgogne*.

Again, the social sustainability of the AS and IS are improved, only because of an improvement of the 'interaction with society' attribute, characterized by the contribution to employment (the numbers of required hours of work for the AS and IS are higher than for the CS) and by the acceptability of the system by society (also estimated better in the AS and IS). Moreover, the landscape perception, also considered in this attribute, was better for the IS systems where landscape management was proposed. Again, differences in the likelihood of adoption could appear, particularly for the IS.

3/ Discussion on DEXiPM assessments of French systems

Overall, the results of the assessment of French systems were coherent with what was awaited. One of the main advantages of DEXiPM is to have in the same model an estimation of most of the aspects of sustainability. However, despite differences within the tree between CS and AS or IS, the model shows a problem of sensitivity to basic attributes, particularly for the upper criteria. Moreover, the attributes in the tree are not always sensitive to differences in pesticide use, because the model consider other aspects of crop management and context such as impact of fertilizers, tillage, etc. involved in the overall sustainability. The higher the number of attributes is in the tree, the less sensitive to each basic attribute the model is. Further study on the sensitivity of the model should be carried out. French AS and IS systems showed a systematic decrease of the yield, and a decrease of the gross margin for AS and IS systems in *Bourgogne* and *Poitou Charentes*. This also needs to be confirmed but the decrease of the gross margin is of course problematic for farmers, and the decrease of yield could not be tolerated by farmers and collecting firms and be very problematic in some context. But the multi-criteria assessments with DEXiPM allow also to discuss the possible levers that can be used: For example, the gross margin is lower for a given economical context (prices, subsidies, etc.), but if systems demonstrate that environmental sustainability is improved, proposals can be made to decision makers to support these systems. Finally, DEXiPM is one of the only models attempting to represent the social sustainability, and the first results of assessment will allow improving the social tree.

No system can be “the best” for all aspects of overall sustainability. However, compromise systems can be identified for which at least one or two pillars of sustainability (economical, environmental, social) are improved. This seems to be the case for IS systems. Moreover, the environmental sustainability is greatly improved for both IS as well as for the AS, also for energy consumption and biodiversity. This is a step further to the reduction of pesticides. The economical sustainability has to be improved for AS in *Poitou Charentes* and IS in *Bourgogne*, even if economical results for the IS in *Bassin Parisien* show that IS in regions with high yield potential can be viable and equivalent to CS. Economical assessment results could urge the decision makers to propose subsidies based on environmental results, in order to improve the economical sustainability of AS and IS.

To conclude, DEXiPM should not be seen as a model to score the sustainability of the system, but more as a discussion tool within the group to reveal advantages and weaknesses of systems proposed by partners, and think about options to improve the weakness points.

Cross-country analysis using DexIPM

It was hoped that the DexIPM programme could be used to do a cross-country comparison of the CS , AS and IS1 systems for all three countries (France, Denmark and the UK). However, it became clear that some of the weightings for model parameters needed to be adapted to suit the circumstances within each individual country. Moreover, the proposed AS and IS1 systems for the three different countries were considered to be too different for any cross-country analysis to be meaningful. For these two reasons a cross-country analysis was not done. Nevertheless, a few common principles and contrasts can usefully be drawn between DEXiPM analyses of AS and IS systems in different countries.

DEXiPM detected a clear trend towards improved environmental sustainability in the proposed systems in France and the UK, but it did not detect a further increase in this indicator in Danish systems, even though the TFI in Denmark was reduced (from an already low base).

Economic sustainability was reduced in some AS or IS1 systems from all three countries, according to DEXiPM, even though the approaches to AS and IS design differed radically. DEXiPM suggested that, even though profitability remains the same in all three Danish systems, the economic sustainability of AS and IS is less robust because of the lower value of crops in the proposed systems, which leads to increased risk and reduced investment capacity. Likewise, in the French AS and IS systems where gross margin was reduced (Bourgogne and Poitou-Charentes, respectively), the reduced economic viability appears to be due to reduced yields and reduced selling prices for the crops grown. The same factors are likely to apply in the UK AS, where spring crops are included, and must be accentuated in the tested version of IS1, which includes a fallow for management of weed resistance but which gives no harvest.

The social sustainability of AS and IS systems in the UK and Denmark was rated by DEXiPM analysis to have improved no further compared to CS, which in both countries already achieve a high score for this very broad indicator of social acceptability and benefit. In the UK, however, several social indicators rated AS and IS systems to be easier for farmers to operate. DEXiPM analysis of AS and IS systems in France indicated that social sustainability was improved compared to CS due to improved ‘interaction with society’ (contribution to employment) and improved acceptability to society (including landscape improvement). However, more operational difficulties were associated with the IS in Bassin Parisien due to the larger number of agronomic operations (especially tillage) and the potential for clashes in time.

All three countries considered DEXiPM assessments to have made a useful contribution to the discussion of the strengths and weaknesses of their AS and IS systems and to highlighting areas where improvement is needed.

Discussion

The proposals for advanced and innovative systems to reduce the use of pesticides were remarkably different in these three north European countries, leading to some difficulty in finding a common vocabulary to describe AS and IS. Two approaches to designing innovative cropping sytems were identified:

i. Innovative systems devised by modifying the existing CS, reducing pesticide use through the introduction of both low-tech practices (e.g. optimized/adjusted dosages, sowing densities and dates, cultivars, crop sequences, tillage, etc.) and hi-tech practices (e.g. GPS-guided applications, pesticide targeting, decision support systems). This approach relies on a mix of preventative and curative pest management and was adopted by the UK and Denmark,

ii. Innovative systems developed from a cropping system with no pesticide (e.g. organic CS) relying on all possible low technology means to control pests, pesticides only being added when alternative practices fail. This approach firmly emphasizes preventative measures, re-designing the whole cropping system to limit the risk of pest attacks, and was adopted by France.

A consequence of these different approaches to innovative system design, together with the different local contexts for which they were designed, is that comparison of systems between countries is difficult. For example, the introduction of alfalfa is possible in French systems because of the presence of cattle on farms but it would not be possible in Danish systems where the crop would have no use. Danish farmers, by contrast, must maintain sufficient barley in their crop sequence to be able to feed pigs. Moreover, the lines between AS and IS were drawn differently in each country. For example, species intercropping was considered as an advanced practice in France as it is already commonly practiced in organic farming, whereas it was considered as innovative in Denmark and not included at all in UK systems. Mechanical weeding is one of the options for advanced systems in France but is considered only for innovative systems in Denmark and the UK. Wild flower margins were considered for AS in the UK (where they are increasingly in use already) whereas they are proposed for innovative systems in France.

The different approaches in different countries arise from the socio-economic and pedo-climatic contexts in each country and from the priority given to the constraints imposed by those contexts. The priority given to maintaining profitability and yield in the UK and to continuing to support pig production in Denmark, together with already low TFI levels in Denmark, limited some options for pesticide reduction and favoured a less radical redesign of cropping systems. In France, the very high priority given to reducing TFI, and the suitability of the pedo-climatic conditions for a wider range of crops, allowed a more complete and less constrained redesign of the cropping systems, including radical modification of the crop sequence.

The TFIs of current systems varied greatly between countries, France and the UK currently having relatively high TFI in all crops compared to Denmark. As a result, there is more scope for TFI reduction in France and the UK and, to realize this, the proposed advanced and innovative systems for those countries were more different from their current systems than were the innovative systems for Denmark. For example, crops such as hemp or alfalfa were proposed in the French systems and fallows were an option for weed management in the British systems.

The results of DEXiPM assessment of innovative cropping systems differed between countries but perhaps less than might be expected given the different approaches to design and the differing levels of crop diversity proposed. Although Denmark achieved the lowest levels of TFI, DEXiPM indicated no improvement in overall levels of environmental sustainability, whereas IS systems in UK and France achieved improvements from 'low' to 'medium' for that score. The radically re-designed systems were in France not more environmentally sustainable than those less radically redesigned in the UK and, in common with the UK and Danish IS, presented economic problems that needed to be addressed. Findings of this kind are of value for indicating where there may be a role for policies (taxes, subsidies, etc.) to improve social and economical sustainability of environmentally successful systems.

DEXiPM multi-criteria assessment was intended to highlight problems that needed to be improved. It was a useful framework for structuring comparison of the sustainability and performance of the CS, AS and IS1 systems within countries and for highlighting areas where improvement is needed. However DEXiPM does not purport to replace a full and objective socio-economic and environmental impact assessment.

The present exercise has been a useful examination of what pesticide reduction might be achieved on farms and how and with what local consequences. Yet the proposed changes in cropping systems could have significant political implications, for example in relation to policy instruments necessary for their implementation and perhaps even in relation to markets, prices and food security. For example, what would be the cost to the taxpayer of promoting more sustainable farming systems that might be less economically sustainable, and what would be the wider consequence of a reduction in wheat production on farms in the UK adopting AS or IS? Such wider-scale implications of the AS and IS proposals have not been considered here and should form part of a future, more in-depth socieconomic analysis and assessement.

The process of development of higher level innovative systems (IS2) for futher pesticide reduction should lend itself to a different approach to design. IS2 systems would have a 10-20 year time horizon for implementation, integrating technologies now still in development. In this circumstance, it would be more appropriate to agree common principles acceptable in all three countries.

Conclusions

We conclude that there is considerable scope for reductions in pesticide use by employing agronomic methods and technologies that are already available to farmers, or are close to being so, but that this scope varies greatly between countries depending upon how much pesticide usage has already been reduced and upon the local socio-economic and pedo-climatic context. The estimated maximum TFI reductions achieved by IS1 in Denmark, France and the UK were 37%, 94% and 56%, respectively, and it should be stressed that the reduction in Denmark is achieved from an already very low base-line. As a result of different local conditions and different approaches to system design, proposed AS and IS1 systems varied greatly between countries and direct comparisons were difficult. Nevertheless, DEXiPM analysis of the systems in the three countries suggested that France and the UK had been successful in designing systems with improved overall environmental sustainability compared to their current systems and that all countries had achieved improved or sustained social benefits. However, in at least some proposed systems in all countries, DEXiPM analysis suggested that environmental and social benefits were achieved at the cost of reduced economic sustainability of the proposed system. A full, objective socio-economic and environmental impact assessment of the proposed systems is essential if the implications of their implementation are to be adequately understood.

References

Aubertot, J.N., Barbier, J.M., Carpentier, A., Gril, J.J., Guichard, L., Lucas, P., Savary, S., Savini, I., Voltz, M., 2005. Pesticides, agriculture et environnement. Réduire l'utilisation des pesticides et limiter leurs impacts environnementaux. Rapport d'expertise scientifique collective, INRA et CEMAGREF.

Clarke J, Moss S. & Orson J. (2000) The future for grass weed management in the UK. *Pesticide Outlook* – April 2000, 59-63.

Guichard, L., 2008. PERSYST, un outil d'évaluation des performances agronomiques et environnementales des systèmes de culture. Livrable du SP1 Praiterre.

Guichard, L., Savini, I., Brunet, N., Debaeke, P., Delos, M., Guérin, O., Guindé, L., Mischler, P., Munier-Jolain, N., Omon, B., Rolland, B., Viaux, P., Villard, A., 2009. ECOPHYTO R&D, vers des systèmes de culture économes en produits phytosanitaires. VOLET 1, TOME II: Analyse comparative de différents systèmes en grandes cultures. Rapport d'expertise, INRA Editeur.

Jørgensen, LN & Kudsk P (2006) Twenty years' experience with reduced agrochemical inputs. In: *Proceedings Home Grown Cereal Authority, Research & Development Conference. Arable Crop Protection in the Balance Profit and the Environment, 25-26 of Jan. 2006,* Lincolnshire, UK, 16.1-16.10.

Melander B. (1995). Impact of drilling date on *Apera spica-venti* L. and *Alopecurus myosuroides* Huds. in winter cereals. *Weed Research* **35**, 157-166.

Melander B., Holst N., Jensen P.K., Hansen E.M. & Olesen J.E. (2008). *Apera spica-venti* population dynamics and impact on crop yield as affected by tillage, crop rotation, location and herbicide programmes. *Weed Research* **48**, 48-57.

Orson J.H. (2006) Weed and pest management. In: *Extended* a*bstracts NJF (Nordic Association of Agricultural Scientists) Seminar 378*, Odense, Denmark, 46-53 (http://www.njf.nu/seminars/378/).

Schmidt, A. (2009). Caractérisation des pratiques de protection des cultures et réflexions sur les conditions de réussite d'un plan de réduction de l'utilisation de produits phytosanitaires par les pouvoirs publics, a*pplication à la production de blé et de colza*. AgroParisTech report.

Valantin-Morison M., Meynard JM., Doré T. 2006a. Crop management and environment effects on insects in organic winter oil seed rape (WOSR) in France. Crop protection 26 : 1108-1120

Valantin-Morison M., Quere L. 2006b. Effects of turnip rape trap crops on oilseed rape pests in a network of organic farmers' fields. *Congress of European Project MASTER, Integrated pest mangement* Göttingen (Allemagne), 2006/04/2-5

Appendix A: AS and IS1 systems for each country

Denmark, AS

Principles: *principles of AS-systems proposed with regard to the main pest risk identified in the current system*

Pest	Scale	Main crop protection strategies, main principles	Aim Impact on pests	Others impacts disadvantages & advantages
WEEDS	**Cropping system**	Diversifying sowing periods by introducing spring crops and shifting sowing dates (early/late sowing dates)	Prevent the proliferation of cleavers (*Galium aparine*) and specialised annual grass weeds Allows stale seedbed between harvest and drilling (late sowing or spring crops)	The percentage of high yield crops (e.g. wheat) in the rotation cannot be maintained. Energy and time consumption may increase (false seedbed) Risk of NO_3 leaching, especially with bare soil (prior to spring crops) Positive impact on diseases (sowing dates and diversified rotations)
		Prioritise crop cultivars with high disease resistance	Reduces the incidence of diseases	Delivery constraints for some crops
		Mechanical cultivation prior to sowing including ploughing (inverting tillage)	Reduces TFI	Energy and time consumption may increase Ploughing may reduce natural enemies
	All crops	Reduced herbicide dose through field assessments and optimised application timing supported by a decision support system	Reduces TFI	Control failures leading to a high weed seed return
	Crop: Winter oil seed rape	Inter-row cultivation	Reduces TFI, controls weeds	May decrease slug incidence
	Crop: winter wheat	Delayed sowing	Reduces emergence of winter annual weeds	Also efficient to decrease aphids causing Barley Yellow Dwarf Virus (BYDV) (no autumn insecticide against aphids, less fungicide). Slug problems may increase Risk of lower yield Risk of unsuitable sowing conditions
	Crop: spring barley	Placement of fertilizers	Increases weed suppression	Equipment for placement needed
		Early sowing of high priority	Competition against spring weeds	Unsuitable weather / soil conditions for sowing
INSECTS PESTS	**Landscape**	No specific changes proposed		
	All crops	Spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing	Reduce TFI	Control failures may occur
DISEASE	**Cropping system**	Diversifying crops in the rotation	Increase duration between the same crop	Lower frequency of highly valuable crops

	All Crops	Use of resistant cultivars against diseases	Reduces TFI	Resistant cultivars sometimes less productive Delivery constraints with cultivars
		Reduced fungicide dose through field assessments and optimised application timing supported by a decision support system	Reduces TFI	Control failures may occur
	Crop: Winter wheat	Delayed sowing	Limit aphids and thus BYDV	Risk of lower yield Risk of unsuitable sowing conditions
SLUGS	**Crops**	Export straws if possible	Reduce TFI	Decrease of soil organic matter

LANDSCAPE MANAGEMENT PRACTICES

Landscape management	**Period**	**Practice**	**DEXiPM inputs**	**Observations**
Field margin		No specific changes from the current situation	Habitat management	
Non-productive area		No specific changes from the current situation	Habitat management	
Other landscape management that could be mentioned, not in the present system				
Surrounding fields		*Stubble management (stubble as source of inoculum for new fields, e.g. phoma stem canker), Species and cultivars choice and distribution at the landscape scale (collective management of resistance durability, GM management), etc...*	*Pest pressure includes cultivar distribution*	

CROP MANAGEMENT PRACTICES

Crop management	**Period (decade)**	**Practice and description**	**DEXiPM inputs (described in detail in the attached table)**	**Impact on pests**	**Disadvantages**	**Pesticide reduction**
CROP SEQUENCE		I. W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley II. W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop / undersown ley – S. barley	No of crops, proportion of summer crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover			
Pre-drilling tillage	August-September (just after harvest of	Stale seedbed and stubble breaking (cover crop) No of operations: 1-3 Specified for each crop	Superficial tillage between crops	Favour emergence of volunteers and *Bromus* species	Mineralization	Reduction of herbicides especially those with effects against grasses

	preceding crop)					
		Deep tillage: no, max. 25 cm	Deep tillage	Preserve soil natural enemies		
		Inversion tillage: yes	Tillage type (inversion)	Weed control in general	May reduce natural enemies	Lowers the need for gramicides
CROP 1: winter barley	Weeds: delayed sowing, reduced herbicide dose through field assessments and optimised application timing supported by a decision support system Diseases: delayed sowing to reduce BYDV, resistant cultivars, reduced fungicide dose through field assessments and optimised application timing supported by a decision support system Insects pests: insecticides against aphids, if necessary Potential pesticide reduction in relation to current practises: 5-10%					
Pre-drilling tillage	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Drilling	Mid-September	Criteria for variety choice ranked according to priority: 1) winter hardiness, 2) yield, 3) lodging, 4) rust (*Puccinia hordei*), 5) net-blotch (*Drechlera teres*). Among pests: main focus on disease resistance	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level of rust and net-blotch	Varieties not always available. The other factors may compromises disease resistance	50% reduction of fungicide use in comparison with a susceptible variety provided that resistant varieties are available
	Mid-September	Delayed sowing, 10-14 days	Superficial tillage between crops	Reduced incidence of Barley Yellow Dwarf Virus (BYDV) and reduced emergence of winter annual weeds	May increase slug problems on clay soils	50% insecticide reduction on 50% of the area, if warnings confirm a risk for aphid attacks
	Mid-September	Decrease seed rate, 250 pl m^{-2}	Sowing density	Reduces risk of lodging	Increased risk of weed growth	Little potential for reduction as there is only minor use of plant growth regulators (PGR)
Mineral fertilization	Early April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 60 K	Mineral P/K fertilizers applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 160 N	Mineral N fertilizer applications Total number of treatment			

			operations			
Organic fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	October	Soil active herbicide	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Annual grass weeds and broadleaved weeds	Optimal timing can be obstructed by unfavourable weather conditions. Farming structures with large areas to be treated can also have a negative effect on timing.	Early application optimizes possibilities to apply reduced rates and product mixtures according to the weed flora. Mixtures and correct timing can potentially reduce herbicide input by 25%
	April	Foliage active herbicide	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Primary broad leaved weed control. Occasionally wild oat and remaining grass weeds	Optimal timing can be jeopardised by unfavourable weather conditions and farm structures	Field assessment determines the need. If proper autumn treatment has been made, the need for control will decline. Only 20-30% of the area normally treated would be treated, if spraying decisions are based on field assessment
	Early July	Pre-harvest Couch (*Elymus repens*) control with glyphosate	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Couch control. Other perennials are affected and crop desiccation is achieved	None	Field assessment determines the need. Patch spraying, reduction potential up to 90%

Fungicide	May	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, net-blotch, mildew (*Erysiphe spp*.), leaf scald (*Rhynchosporium secalis*)	None	Field assessment determines the need. Optimised timing and dose. Reduction potential already achieved in practise
Insecticide	Early October	Insecticide against BYDV	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Aphid control		If applied, then only according to risk. Treatments can be avoided in some years
Growth regulator		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Other chemical product		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Mid-end July	Operation: classic (no additional cost) No of operation: 1 Expected yield: 6 t ha^{-1}	Fuel consumption at harvest			
POST-HARVEST	End July	Stubble breaking (cover crop)	Superficial tillage	To reduce volunteers in		Reduction of herbicide

MANAGEMENT/ pre drilling tillage		No of operations: 2	between crops	the subsequent crop		
Intermediate crop		No				
CROP 2: winter oil seed rape	Weeds: mechanical weeding, spring herbicide if necessary, volunteer control by light stubble cultivation Diseases: chemical control, resistant varieties Insects: chemical control according to field assessments and warning systems Slugs: mechanical weeding, chemical control Potential pesticide reduction in relation to current practises: 30-50%					
Drilling	Early-mid August	Criteria for variety choice ranked according to priority: 1) winter hardiness, 2) yield, 3) seed price	Additional seed cost of cultivar, yield reduction due to cultivar		Little information on disease resistance among varieties	Documentation is lacking
	Early-mid August	Establishment on increased row spacing, preferably 50 cm. Plant density: 20-25 plants m^{-1}	Superficial tillage between crops		Early sowing might increase the need for plant growth regulation (PGR). Phoma may increase. However, of minor importance	See description for inter-row cultivation
		Density: 20-25 plants m^{-1}	Sowing density			
Mechanical weeding	Mid-September	1-2 inter-row cultivations	Superficial tillage in crops	Weed control in general. May reduce slug incidence	Availability of machinery, low capacity, weather dependency Insufficient effect against high levels of volunteers and grass weeds in the rows	80% herbicide reduction. Lower need for PGR although not commonly used
Mineral Fertilization	Mid March	No of operations: 1 Standard total amount kg ha^{-1}: 25 P, 80 K	Mineral P/K fertilizer applications Total number of treatment operations			
	Mid-September / Mid-March	No of operations: 1-2 Total amount kg ha^{-1}: 180 N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No		Late sowing		

Herbicide	Ultimo April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Mayweed *Tripleurospermum inodorum*	None	Field assessment determines the need. Potentially 50% reductions with patch spraying
Fungicide	Early October	Chemical phoma control (*Phoma lingam*)	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Phoma + PGR	None	If high level of nutrients from slurry, PGR application might be relevant
	May	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Sclerotinia stem rot (*Sclerotinia sclerotium*), alternaria spp., grey rot (*Botrytis cinerea*)	None	No reductions possible due to lack of efficient warning systems
Insecticide	September	Chemical slug control following inter-row cultivation and only on loam/clay soils	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Slugs	None	According to alerts from a warning system on field level
	Early October	Chemical cabbage stem flea beetle (*Psylliodes chrysocepthala*) control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of	Cabbage stem flea beetle	None	According to alerts from a warning system on field level

			treatment operations			
	Medio-ultimo April	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pollen beetle (*Meligethes aeneus*)	None	Field assessment determines the need. 30% reduced dose currently used
	May	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Cabbage seed weevil, (*Ceutorhynchus assimilis*) & Brassica pod midge (*Dasineura brassicae*)	None	Field assessment determines the need. 30% reduced dose currently used
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Mid July	Operation: classic (no additional cost) No : 1 Expected yield: 3.4 t ha^{-1}	Fuel consumption at harvest			
		Straws exported	Stubble management	Avoid slugs		No molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	End July / early august	Stubble breaking (cover crop) No of operations: 2	Superficial tillage between crops	To reduce volunteers in the subsequent crop		Reduction of herbicide
	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Intermediate crop		No				
CROP 3 and 4 in rotations I and II:	Weeds: delayed sowing, reduced herbicide dose through field assessments and optimised application timing supported by a decision support system Diseases: resistant variety, reduced fungicide dose through field assessments and optimised application timing supported by a decision support system					

winter wheat	Insects: resistant variety, spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing Lodging: reduced crop density Potential pesticide reduction in relation to current practises: 5-10%					
Drilling	September	Criteria for variety choice ranked according to priority: 1) winter hardiness, 2) yield, 3) lodging tendency, 4) rust (*Puccinia spp.*), 5) Septoria tritici, 6) mildew (*Erysiphe spp.*), among pests main focus on disease resistance	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level of the diseases mentioned	Varieties not always available. The other criteria may compromise disease resistance	50% reduction of fungicide use in comparison with a susceptible variety provided that the resistant varieties are available
		Delayed sowing 10-14 days	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced incidence of Barley Yellow Dwarf Virus and reduced emergence of winter annual weeds	May increase slug problems on clay soils	50% insecticide reduction on 30% of the area, if warnings confirm risk of aphid attacks
		Decreased density: 250-300 pl. m^{-2}	Sowing density	Reduces the risk of lodging	Increased risk of weed growth	Small potential for reduction as there is relatively little use of PGR
Mechanical weeding		No	Superficial tillage in crops			
Mineral Fertilization	Early April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 60 K	Mineral P/K fertilizers applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 120 N for crop 3 and 160 N for crop 4	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No				
Herbicide	October	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility	Weed control, especially against grass weeds	Optimal timing can be jeopardized by unfavourable weather	Early application optimizes the possibilities to apply reduced rates and

			Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		conditions and farm structures and lack of sufficient capacity	product mixtures according to the weed flora. Mixtures and correct timing may result in a 25% reduction
	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Primary broad leaved weeds. Occasionally wild oat (*Avena fatua* L.) and remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and farm structures and lack of sufficient capacity	Field assessment determines the need. If a proper autumn treatment has been made, the need will decline. Only 20-30% of the area would be treated, if decisions about spraying are based on field assessments
	Primo July	Pre-harvest Couch (*Elymus repens*) control with glyphosate. Applied in the winter wheat crop in the rotation in 50% of the cases	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Couch control. Other perennials and desiccation of the crop	None	Field assessment determines the need. Reduction potential up to 90% with patch spraying
Fungicide	May-June	Chemical disease control, 1-2 treatments	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, mildew, septoria	None	Field assessment determines the need. Optimised timing and dose in practise. Reduction potential already achieved
Insecticide	Early October	Insecticide against BYDV	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Aphid control (e.g. *Sitobion avenae*)	None	If applied then only according to risk. Treatments can be avoided in some years
	June	Chemical pest control	TFI of insecticide	Aphids / orange wheat	None	Field assessments,

			Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	blossom midge (*Sitodiplosis mosellana*)		resistant varieties against orange wheat blossom midge
Growth regulator	April	Chemical control, Plant Growth Regulation	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Decreased risk of lodging	None	N-limitations, variety choice, seed rate and sowing date influence the need for PGR
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No				
Harvest	End of August	Operation: classic (no additional cost) No : 1 Yield 7.2 t ha^{-1}	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage between crops 3 and 4	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Catch crop after crop 4	Late August	Catch crop		Suppresses weed growth in the autumn		Unknown
CROP 5 in rotation I: spring barley CROP 5 and 6 in rotation II: spring barley	Weeds: fertiliser placement, reduced herbicide dose through field assessments and optimised application timing supported by a decision support system Diseases: resistant variety, reduced fungicide dose through field assessments and optimised application timing supported by a decision support system Insects: spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing Potential pesticide reduction in relation to current practises: 10-30%					
Drilling	March-April	Criteria for variety choice ranked according to priority: 1) yield, 2) quality, 3) rust, 4) net-blotch.	Superficial tillage between crops	Reduced disease level of rust and net-blotch	Varieties not always available. The other factors may compromise	50% reduction of fungicide use in comparison with a

		Among pests main focus is on disease resistance			disease resistance	susceptible variety provided that resistant varieties are available
	Density: 300-350 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	Reduced herbicide dose may become more efficient
Mechanical weeding		No				
Mineral Fertilization	March-April	Placement of nutrients	Mineral N/P/K fertilizer applications Total number of treatment operations	Improved crop competitiveness against weeds	None	25% reduction in herbicide input
	March-April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 50 K	Mineral P/K fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 120 N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		No				
Herbicide	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Primary broad leaved weeds. Occasionally wild oat (*Avena fatua* L.) and remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and farm structures and lack of sufficient capacity	Field assessment determines the need. Optimal timing can reduce the dose by 20-30%
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, net-blotch, mildew, leaf scald (*Rhynchosporium secalis*)		Field assessment determines the need. Optimised timing and dose in practise, reduction potential already achieved
Insecticide	May	Chemical pest control	TFI of insecticide	Aphids, cereal leaf beetle		Field assessment,

			Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	(*Oulema spp.*)		spraying according to the need
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Harvest	Mid-August	Operation: classic (no additional cost) No : 1 Yield 4.9 t ha^{-1}	Fuel consumption at harvest		
Catch crop after crop 5 in rotation II	Late August	Catch crop		Suppresses weed growth in the autumn		Unknown

Denmark IS1-systems (differences from AS are written in bold)

Principles: *principles of the IS1s proposed with regard to the main pest risk identified in the current system*

Pest	Scale	Main crop protection strategies, main principles	Aim Impact on pests	Others impacts disadvantages & advantages
WEEDS	**Cropping system**	Diversifying sowing periods by introducing spring crops and shifting sowing dates (early/late sowing dates)	Prevent the proliferation of cleavers (*Galium aparine*) and specialised annual grass weeds Allows stale seedbed between harvest and drilling (late sowing or spring crops)	The percentage of high yield crops (e.g. wheat) in the rotation cannot be maintained. Energy and time consumption may increase (false seedbed) Risk of NO_3 leaching, especially with bare soil (prior to spring crops) Positive impact on diseases (sowing dates and diversified rotations)
		Prioritise crop cultivars with high disease resistance	Reduces the incidence of diseases	Delivery constraints for some crops
		Mechanical cultivation prior to sowing including ploughing (inverting tillage)	Reduces TFI	Energy and time consumption may increase Ploughing may reduce natural enemies

	All crops	Reduced herbicide dose through field assessments and optimised application timing supported by a decision support system	Reduces TFI	Control failures leading to a high weed seed return
	Crop: Winter oil seed rape	Inter-row cultivation	Reduces TFI, controls weeds	May decrease slug incidence
	Crop: winter wheat	Delayed sowing	Reduces emergence of winter annual weeds	Also efficient to decrease aphids causing Barley Yellow Dwarf Virus (BYDV) (no autumn insecticide against aphids, less fungicide). Slug problems may increase Risk of lower yield Risk of unsuitable sowing conditions
	Crop: spring barley	Placement of fertilizers	Increases weed suppression	Equipment for placement needed
		Early sowing of high priority	Competition against spring weeds	Unsuitable weather / soil conditions for sowing
INSECTS PESTS	**Landscape**	Small fields (<10 ha), settlement of hedges or other non-productive areas	Favour natural enemies	
		Flowering strips for pollinators (syrphae), refuges for ladybugs in winter	Favour natural enemies populations against aphids	
		Turnip rape (*Brassica rapa*) on WOSR margins	Attract pollen beetles	Loss of productive area
	All crops	Spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing	Reduce TFI	Control failures may occur
DISEASE	**Cropping system**	Diversifying crops in the rotation	Increase duration between the same crop	Lower frequency of highly valuable crops
	All Crops	Use of resistant cultivars against diseases	Reduces TFI	Resistant cultivars sometimes less productive Delivery constraints with cultivars
		Reduced fungicide dose through field assessments and optimised application timing supported by a decision support system	Reduces TFI	Control failures may occur
	Crop: Winter wheat	Delayed sowing	Limit aphids and thus BYDV	Risk of lower yield Risk of unsuitable sowing conditions
SLUGS	**Crops**	Export straws if possible	Reduce TFI	Decrease of soil organic matter

IS1 prototype

LANDSCAPE MANAGEMENT PRACTICES

Landscape management	**Period**	**Practice**	**DEXiPM inputs**	**Observations**
Field margin		**Trap cropping. Flowering bordering zones to trap insects**	**Habitat management**	**Breaking at flowering to kill part of the pollen beetle**
Non-productive area		**Hedges, flowering strips…**	**Habitat management**	**Increase natural enemies populations**
Landscape (fields, margins, and non-productive areas)		**Stewardship schemes**	**Societal value of landscape**	**Landscape perception**
Other landscape management that could be mentioned, not in the present system				
Surrounding fields		*Stubble management (stubble as source of inoculum for new fields, e.g. phoma stem canker), Species and cultivars choice and distribution at the landscape scale (collective management of resistance durability, GM management), etc…*	*Pest pressure includes cultivar distribution*	

CROP MANAGEMENT PRACTICES

Crop management	**Period (decade)**	**Practice and description**	**DEXiPM inputs (described in detail in the attached table)**	**Impact on pests**	**Disadvantages**	**Pesticide reduction**
CROP SEQUENCE		I. W. barley – W. rape – W. wheat – W. wheat + catch crop – S. barley II. W. barley – W. rape – W. wheat - W. wheat + catch crop – S. barley + catch crop / undersown ley – S. barley	No of crops, proportion of summer crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover			
General management of crop protection		**<u>Logistics</u>: optimisation of systems to manage logistics at farm level: improves timing, capacity and rounding off of areas because the work is better organised**		**Better effects are expected because timing of applications are improved**		**0-5% reduction in pesticide input**
		<u>Spraying technology</u>: spraying equipment with higher capacity. GPS-systems introduced to avoid overlapping, 5 % savings in pesticide use in Danish farm test. Whenever possible spraying				**Overlapping and non-target areas are avoided**

		should be based on weed mapping and patch spraying				
		Improved forecasting models and decision support systems		**More targeted treatments with better timing**		**The reduction potential unknown**
Pre-drilling tillage	August-September (just after harvest of preceding crop)	Stale seedbed and stubble breaking (cover crop) No of operations: 1-3 Specified for each crop	Superficial tillage between crops	Favour emergence of volunteers and *Bromus* species	Mineralization	Reduction of herbicides especially those with effects against grasses
		<u>Dynamic tillage</u>: various depths, tillage according to need and problem	**Deep tillage**	**Preserve soil natural enemies, control pests**		**Lower need for pesticides in general**
		Inversion tillage: yes/no	**Tillage type (inversion/non-inversion)**	**Weed control in general. Less crop residues**	**May reduce natural enemies.**	**Lowers the need for gramicides**
CROP 1: winter barley	Weeds: delayed sowing, reduced herbicide dose through field assessments and optimised application timing supported by an **improved** decision support system decision support system. **Prevention of weed seed return during harvesting** Diseases: delayed sowing to reduce BYDV, **variety mixtures** with resistant cultivars, reduced fungicide dose through field assessments and optimised application timing supported by a **improved** decision support system. **Adjusted fungicide dosage according to crop biomass** Insects pests: insecticides against aphids, if necessary. **Improved forecasting models, especially against aphids**					
Pre-drilling tillage	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Drilling	Mid-September	**Variety mixtures that minimises disease attack relative to single varieties. Resistance against 1) rust (*Puccinia hordei*) and 2) net-blotch (*Drechlera teres*) of particular interest**	**Additional seed cost of cultivar, yield reduction due to cultivar**	**Avoid high disease levels**	**Varieties not always available. Factors such as yield, winter hardiness and lodging may compromises disease resistance**	
	Mid-September	Delayed sowing, 10-14 days	Superficial tillage between crops	Reduced incidence of Barley Yellow Dwarf Virus (BYDV) and reduced emergence of winter annual weeds	May increase slug problems on clay soils	50% insecticide reduction on 50% of the area, if warnings confirm a risk for aphid attacks

	Mid-September	Decrease seed rate, 250 pl m^{-2}	Sowing density	Reduces risk of lodging	Increased risk of weed growth	Little potential for reduction as there is only minor use of plant growth regulators (PGR)
Mineral fertilization	Early April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 60 K	Mineral P/K fertilizers applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 160 N	Mineral N fertilizer applications Total number of treatment operations			
Organic fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	October	Soil active herbicide	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Annual grass weeds and broadleaved weeds	Optimal timing can be obstructed by unfavourable weather conditions. Farming structures with large areas to be treated can also have a negative effect on timing.	Early application optimizes possibilities to apply reduced rates and product mixtures according to the weed flora. Mixtures and correct timing can potentially reduce herbicide input by 25%
	April	Foliage active herbicide	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Primary broad leaved weed control. Occasionally wild oat and remaining grass weeds	Optimal timing can be jeopardised by unfavourable weather conditions and farm structures	Field assessment determines the need. If proper autumn treatment has been made, the need for control will decline. Only 20-30% of the area normally treated would be treated, if spraying

						decisions are based on field assessment
	Early July	Pre-harvest Couch (*Elymus repens*) control with glyphosate	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Couch control. Other perennials are affected and crop desiccation is achieved	None	Field assessment determines the need. Patch spraying, reduction potential up to 90%
Fungicide	May	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, net-blotch, mildew (*Erysiphe spp*.), leaf scald (*Rhynchosporium secalis*)	None	Field assessment determines the need. Optimised timing and dose. Reduction potential already achieved in practise
Insecticide	Early October	Insecticide against BYDV	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Aphid control		If applied, then only according to risk. Treatments can be avoided in some years
Growth regulator		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Other chemical product		No	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment			

			operations			
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Mid-end July	Operation: classic (no additional cost) No of operation: 1 Expected yield: 6 t ha^{-1}	Fuel consumption at harvest			
		Harvest techniques: collecting weed seeds during harvest operation, spot mapping of individual weed species during harvest operation	**Fuel consumption at harvest**	**Prevention of weed seed return – less future weed problems**		**Reduction potential unknown**
POST-HARVEST MANAGEMENT/ pre drilling tillage	End July	Stubble breaking (cover crop) No of operations: 2	Superficial tillage between crops	To reduce volunteers in the subsequent crop		Reduction of herbicide
Intermediate crop		No				
CROP 2: winter oil seed rape	Weeds: mechanical weeding, spring herbicide if necessary, volunteer control by light stubble cultivation. **Band-spraying**. **Prevention of weed seed return during harvesting** Diseases: chemical control, resistant varieties. **Adjusted fungicide dosage according to crop biomass** Insects: chemical control according to field assessments and warning systems. **Improved forecasting models** Slugs: mechanical weeding, chemical control					
Drilling	Early-mid August	Criteria for variety choice ranked according to priority: 1) winter hardiness, 2) yield, 3) seed price	Additional seed cost of cultivar, yield reduction due to cultivar		Little information on disease resistance among varieties	Documentation is lacking
	Early-mid August	Establishment on increased row spacing, preferably 50 cm. Plant density: 20-25 plants m^{-1}	Superficial tillage between crops		Early sowing might increase the need for plant growth regulation (PGR). Phoma may increase. However, of minor importance	See description for inter-row cultivation
		Density: 20-25 plants m^{-1}	Sowing density			
Mechanical weeding	Mid-September	1-2 inter-row cultivations	Superficial tillage in crops	Weed control in general. May reduce slug incidence	Availability of machinery, low capacity, weather dependency Insufficient effect	80% herbicide reduction. Lower need for PGR although not commonly used

					against high levels of volunteers and grass weeds in the rows	
Mineral Fertilization	Mid March	No of operations: 1 Standard total amount kg ha^{-1}: 25 P, 80 K	Mineral P/K fertilizer applications Total number of treatment operations			
	Mid-September / Mid-March	No of operations: 1-2 Total amount kg ha^{-1}: 180 N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No		Late sowing		
Herbicide	**September**	**Development of band-spraying techniques against intra-row weeds in oilseed rape**	**TFI of herbicide** **Total pesticide TFI** **Pesticide mobility** **Pesticide eco-toxicity** **Soil cover at pesticide application** **Total number of treatment operations**	**Effective against intra-row weeds in contrast to inter-row cultivation**	**Low working capacity**	**Slight increase in herbicide use**
	Ultimo April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Mayweed *Tripleurospermum inodorum*	None	Field assessment determines the need. Potentially 50% reductions with patch spraying
Fungicide	Early October	Chemical phoma control (*Phoma lingam*)	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Phoma + PGR	None	If high level of nutrients from slurry, PGR application might be relevant
	May	Chemical disease control	TFI of fungicide Total pesticide TFI	Sclerotinia stem rot (*Sclerotinia sclerotium*),	None	No reductions possible due to lack of efficient

			Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	alternaria spp., grey rot (*Botrytis cinerea*)		warning systems
Insecticide	September	Chemical slug control following inter-row cultivation and only on loam/clay soils	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Slugs	None	According to alerts from a warning system on field level
	Early October	Chemical cabbage stem flea beetle (*Psylliodes chrysocepthala*) control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Cabbage stem flea beetle	None	According to alerts from a warning system on field level
	Medio-ultimo April	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pollen beetle (*Meligethes aeneus*)	None	Field assessment determines the need. 30% reduced dose currently used
	May	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Cabbage seed weevil, (*Ceutorhynchus assimilis*) & Brassica pod midge (*Dasineura brassicae*)	None	Field assessment determines the need. 30% reduced dose currently used
Growth regulator		No				

Other chemical product		No				
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Mid July	Operation: classic (no additional cost) No : 1 Expected yield: 3.4 t ha^{-1}	Fuel consumption at harvest			
		Harvest techniques: collecting weed seeds during harvest operation, spot mapping of individual weed species during harvest operation	**Fuel consumption at harvest**	**Prevention of weed seed return – less future weed problems**		**Reduction potential unknown**
		Straws exported	Stubble management	Avoid slugs		No molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	End July / early august	Stubble breaking (cover crop) No of operations: 2	Superficial tillage between crops	To reduce volunteers in the subsequent crop		Reduction of herbicide
	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Intermediate crop		No				
CROP 3 and 4 in rotations I and II: winter wheat	Weeds: delayed sowing, reduced herbicide dose through field assessments and optimised application timing supported by an **improved** decision support system. **Prevention of weed seed return during harvesting** Diseases: **variety or species mixtures** with resistant varieties, reduced fungicide dose through field assessments and optimised application timing supported by an **improved** decision support system. **Improved forecasting models against septoria**. **Adjusted fungicide dosage according to crop biomass** Insects: resistant variety, spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing. **Improved forecasting models, especially against aphids** Lodging: reduced crop density					
Drilling	September	**<u>Variety mixtures</u> that minimises disease attack relative to single varieties. Resistance against 1) rust (*Puccinia spp.*), 2) Septoria tritici, 3) mildew (*Erysiphe spp.*), of particular interest**	**Additional seed cost of cultivar, yield reduction due to cultivar**	**Avoid high disease levels**	**Varieties not always available. Factors such as yield, winter hardiness and lodging may compromises disease resistance**	

		<u>Species mixtures</u> as an alternative to variety mixtures: winter wheat and winter peas mixtures	**Additional seed cost of cultivar, yield reduction due to cultivar**	**Less disease attacks in wheat, less aphid attack.**	**Weed problems more uncertain**	**Reduced fungicide use and probably also insecticide**
		Delayed sowing 10-14 days	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced incidence of Barley Yellow Dwarf Virus and reduced emergence of winter annual weeds	May increase slug problems on clay soils	50% insecticide reduction on 30% of the area, if warnings confirm risk of aphid attacks
		Decreased density: 250-300 pl. m^{-2}	Sowing density	Reduces the risk of lodging	Increased risk of weed growth	Small potential for reduction as there is relatively little use of PGR
Mechanical weeding		No	Superficial tillage in crops			
Mineral Fertilization	Early April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 60 K	Mineral P/K fertilizers applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 120 N for crop 3 and 160 N for crop 4	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No				
Herbicide	October	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Weed control, especially against grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and farm structures and lack of sufficient capacity	Early application optimizes the possibilities to apply reduced rates and product mixtures according to the weed flora. Mixtures and correct timing may result in a 25% reduction
	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity	Primary broad leaved weeds. Occasionally wild oat (*Avena fatua* L.) and remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and farm	Field assessment determines the need. If a proper autumn treatment has been made, the need

			Soil cover at pesticide application Total number of treatment operations		structures and lack of sufficient capacity	will decline. Only 20-30% of the area would be treated, if decisions about spraying are based on field assessments
	Primo July	Pre-harvest Couch (*Elymus repens*) control with glyphosate. Applied in the winter wheat crop in the rotation in 50% of the cases	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Couch control. Other perennials and desiccation of the crop	None	Field assessment determines the need. Reduction potential up to 90% with patch spraying
Fungicide	May-June	Chemical disease control, 1-2 treatments	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, mildew, septoria	None	Field assessment determines the need. Optimised timing and dose in practise. Reduction potential already achieved
Insecticide	Early October	Insecticide against BYDV	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Aphid control (e.g. *Sitobion avenae*)	None	If applied then only according to risk. Treatments can be avoided in some years
	June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Aphids / orange wheat blossom midge (*Sitodiplosis mosellana*)	None	Field assessments, resistant varieties against orange wheat blossom midge
Growth regulator	April	Chemical control, Plant Growth Regulation	Total pesticide TFI Pesticide mobility	Decreased risk of lodging	None	N-limitations, variety choice, seed rate and

			Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			sowing date influence the need for PGR
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No				
Harvest	End of August	Operation: classic (no additional cost) No : 1 Yield 7.2 t ha^{-1}	Fuel consumption at harvest			
		Harvest techniques: collecting weed seeds during harvest operation, spot mapping of individual weed species during harvest operation	**Fuel consumption at harvest**	**Prevention of weed seed return – less future weed problems**		**Reduction potential unknown**
POST-HARVEST MANAGEMENT/ pre drilling tillage between crops 3 and 4	Early September	Light stubble cultivation in case of *Bromus* problems	Superficial tillage between crops	Promotes the emergence of *Bromus* species and volunteers, and reduces slugs	Nitrogen mineralization	50% herbicide reduction on 5-10% of the area, mainly saving the treatment against *Bromus*
Catch crop after crop 4	Late August	Catch crop		Suppresses weed growth in the autumn		Unknown
CROP 5 in rotation I: spring barley **CROP 5 and 6 in rotation II: spring barley**	Weeds: fertiliser placement, reduced herbicide dose through field assessments and optimised application timing supported by an **improved** decision support system. **Prevention of weed seed return during harvesting** Diseases: **variety mixtures** with resistant varieties, reduced fungicide dose through field assessments and optimised application timing supported by an **improved** decision support system. **Adjusted fungicide dosage according to crop biomass** Insects: spraying only according to the need, reduced insecticide dose according to warning systems, field assessments and optimised application timing. **Improved forecasting models, especially against aphids**					
Drilling	March-April	**Variety mixtures that minimises disease attack relative to single varieties. Resistance against 1) mildew, 2) rust, and 2) net-blotch (*Drechlera teres*) of**	**Additional seed cost of cultivar, yield reduction due to cultivar**	**Avoid high disease levels**	**Varieties not always available. Factors such as yield, winter hardiness and lodging may compromises**	

		particular interest			**disease resistance**	
	Density: 300-350 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	Reduced herbicide dose may become more efficient
Mechanical weeding		No				
Mineral Fertilization	March-April	Placement of nutrients	Mineral N/P/K fertilizer applications Total number of treatment operations	Improved crop competitiveness against weeds	None	25% reduction in herbicide input
	March-April	No of operations: 1 Standard total amount kg ha^{-1}: 20 P, 50 K	Mineral P/K fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 120 N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		No				
Herbicide	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Primary broad leaved weeds. Occasionally wild oat (*Avena fatua* L.) and remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and farm structures and lack of sufficient capacity	Field assessment determines the need. Optimal timing can reduce the dose by 20-30%
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, net-blotch, mildew, leaf scald (*Rhynchosporium secalis*)		Field assessment determines the need. Optimised timing and dose in practise, reduction potential already achieved
Insecticide	May	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility	Aphids, cereal leaf beetle (*Oulema spp.*)		Field assessment, spraying according to the need

			Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Mid-August	Operation: classic (no additional cost) No : 1 Yield 4.9 t ha^{-1}	Fuel consumption at harvest			
		Harvest techniques: collecting weed seeds during harvest operation, spot mapping of individual weed species during harvest operation	**Fuel consumption at harvest**	**Prevention of weed seed return – less future weed problems**		**Reduction potential unknown**
Catch crop after crop 5 in rotation II	Late August	Catch crop		Suppresses weed growth in the autumn		Unknown

UK, AS

Crop protection strategy: *principle components of the proposed AS according to the main pest risks identified in the current system*

Pest	**Scale**	**Main crop protection tactics**	**Aim** **Impact on pests**	**Others impacts** **disadvantages & advantages**	**Estimated % TFI change compared to an average farmer practicing the Current System (CS)**
WEEDS	**Cropping system**	Introduction of spring crops and greater taxonomic diversity of crops for pest management, especially containment of black grass and other grass weeds. Total herbicide (glyphosate) in February - April pre-drilling or pre-emergence.	Control of weeds: allows use of total herbicide in spring; any inversion cultivation to create seed-bed benefits grass weed (especially black grass) control and reduces weed seed bank. Crop diversification to reduce pest pressure and foster diversity of natural enemies	Advantages: Spreading workload/flexibility Boost yield of following crop Potential value of overwinter stubbles, weeds and volunteers to invertebrates and birds prior to spring beans. Spring crops yield less but gross margin is likely to be less affected due to premiums for milling wheat or malting barley, increased proportion of first wheats and better pest management.	See individual crops
		Minimise tillage and chop straw wherever possible. Before spring crops plough where necessary (in November for cereals, February/March for beans) to prepare for a spring seed-bed and/or for grass weed management especially blackgrass. Minimum tillage before oilseed rape with propyzamide application for black grass control.	Conserve soil-overwintering and epigeal invertebrate seed predators Grass weed control	Advantages of minimising tillage: Less fuel/time Reduce CO_2 emissions Reduce wear of agricultural machinery Preserve soil structure, maintain moisture Conserve soil inhabiting natural enemies of all pests Decrease fertiliser use by increased nutrient cycling Reduce soil erosion and run-off Better control of broad-leaved weeds Disadvantages: perennial weeds more difficult to control with minimised tillage Some increased need for herbicides and molluscides likely.	
		Broadcast OSR seed into cereal stubble or wide row spacing of OSR to minimise necessary tillage.	Conserve soil-overwintering and epigeal invertebrate seed predators	Advantages: As for minimising tillage	
		Use higher seed rates and cultivars	Control weeds by competition to	Advantages: Reduced costs & environmental impact.	See individual crops

		with strong competitiveness where weeds are problematic Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need Spot mapping and targeting of weeds	reduce herbicide resistance pressures Effective pest control, reduce risk of resistance Target herbicide at weeds	Reduced resistance risk Advantages: Reduced costs & environmental impact. Reduced resistance risk Advantages: Reduced costs & environmental impact. Reduced resistance risk	 No change (herbicide) See individual crops
	Crop: Winter wheat	Use higher seed rates and cultivars with strong competitiveness where weeds are problematic Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need Spot mapping and targeting of weeds			-21% herbicide TFI, +22% fungicide TFI because more dense crop is more humid No change (herbicide) -10% herbicide
	Crop: Spring wheat	Use cultivars with strong competitiveness where weeds are problematic. Plough in November if necessary to prepare for a spring seed-bed and for weed management but minimise tillage where possible. Spot mapping and targeting of weeds	Control weeds by competition Target herbicide at weeds	Advantages: Reduced costs & environmental impact Reduced resistance risk Advantages: Reduced costs & environmental impact Reduced resistance risk	-33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid -15% herbicide
	Crop spring barley	Use higher seed rates and cultivars with strong competitiveness where weeds are problematic. Plough in November if necessary to prepare for a spring seed-bed and for weed management but minimise tillage where possible.	Control weeds by competition	Spring crops yield less but gross margin is likely to be less affected (see 'cropping system' above)	-33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid

		Spot mapping and targeting of weeds	Target herbicide at weeds		-15% herbicide
	Crop: spring beans	Plough in February/March if necessary for weed management and to create a seed-bed but minimise tillage where possible. Spot mapping and targeting of weeds	 Target herbicide at weeds	Advantage: Value of overwinter stubbles, weeds and volunteers to invertebrate s and birds. Advantages: Reduced costs & environmental impact Reduced resistance risk	 -30% herbicide
	Crop: Winter OSR	Minimising tillage, where possible broadcasting seed into cereal stubble or drilling into wide-rows (~50 cm) Spot mapping and targeting of weeds Harvest WOSR after swathing	 Target herbicide at weeds	 Eliminates the need for a desiccant	 -10% herbicide -14% herbicide
INSECT PESTS	**Landscape**	Provide non-crop refugia and resources for natural enemies: field scale: beetle banks, wild flower margins, grassy margins, hedges. landscape scale: maintain spatial and temporal diversity of cropping; rotations including an entomophilous flowering crops (WOSR, S beans); diversity of non-crop areas, e.g. woodland, game cover; high connectivity of non-crop habitats to facilitate movement of natural enemies.	Maintain populations of natural enemies for crops by providing them with permanent habitats as sources alternative prey and as refugia from which to colonise cropped areas. Maintain diversity and abundance of natural enemies in the agricultural landscape. Maintain large-scale connectivity of meta-populations of natural enemies to ensure their survival and ability to move in the landscape in order to provide services in cropped areas.		-10% insecticide
	Cropping system	Introduction of spring crops and greater taxonomic diversity of crops	Break "green bridge" for pests Diverse cropping increases the	Potential value of overwinter stubbles, weeds and volunteers to invertebrate predators prior to spring beans. Increased	-5% insecticides

		for pest management,	diversity of resources for natural enemies and their spatial and temporal spread.	taxonomic diversity of crops reduces pest pressure and maintains greater diversity of natural enemies. Flowering crops benefit invertebrate natural enemies and pollinators	
		Minimising tillage where possible.	Conserve soil-overwintering and epigeal natural enemies (invertebrates, and entomopathogens) of insect pests	Advantage: Reduced impact on natural enemies and environment, reduced TFI.	-10% insecticides
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.	Controlling insect pests according to economic thresholds Optimal timing of pest control	Advantages: Conserve invertebrate biodiversity including natural enemies & pollinators, reduced TFI, reduced risk of resistance.	see individual crops (below)
	Crop: winter wheat	Minimising tillage especially before first wheat after OSR.	Conserves important soil-overwintering natural enemies, especially parasitoids of OSR pests.		see cropping system above
		Use of resistant cultivars	Orange wheat blossom midge resistance where available (not in bread-making wheat in 2009)		-12% insecticides
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.			-10% insecticides
	Crop: Spring wheat	Plough if necessary for weed management and to create a seed-bed in spring (in autumn on heavy land) but minimise tillage where possible.			see cropping system above
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.			-10% insecticides

	Crop: Spring barley	Plough if necessary for weed management and to create a seed-bed in spring (in autumn on heavy land) but minimise tillage where possible. Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.			see cropping system above -50% insecticides
	Crop: Spring beans	Minimise tillage where possible.			see cropping system above
	Crop: Winter OSR	Minimising tillage before and after OSR. Where possible broadcasting seed into cereal stubble or drilling into wide-rows (~50 cm) Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.	Minimum tillage after OSR conserves parasitoids of OSR pests as well as epigeal predators.		see cropping system above further -20% insecticide due to conservation of WOSR parasitoids -75% insecticides

DISEASE	**Cropping system**	Introduction of spring crops and greater taxonomic diversity of crops for disease management. Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, where possible using economic thresholds and decision support systems.	Break "green bridge" for diseases. Reduce inoculums carryover from season to season. Reduces TFI	<u>Advantage</u>: reduces resistance risk	-10% fungicides

	Crop: winter wheat	Use of more resistant cultivars		<u>Advantage</u>: reduces TFI, specifically reliance on "azole" fungicides <u>Disadvantage</u>: Some resistant cultivars yield less that non-resistant	-10% fungicides
	Crop: Spring wheat	Use of more resistant cultivars		<u>Advantage</u>: reduces TFI, specifically reliance on "azole" fungicides <u>Disadvantage</u>: Some resistant cultivars yield less that non-resistant	-10% fungicides
	Crop: Spring barley	Use of more resistant cultivars		<u>Advantage</u>: reduces TFI, specifically reliance on "azole" fungicides <u>Disadvantage</u>: Some resistant cultivars yield less that non-resistant	-10% fungicides
	Crop: Spring beans	Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need		<u>Advantage</u>: reduces resistance risk	-10% fungicides
	Crop: Winter OSR	Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.		<u>Advantage</u>: reduces resistance risk	-5% fungicides
SLUGS	**Cropping System**	Where slugs are a severe problem, bale and cart straw and/or plough; roll twice after drilling. Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems. Conserving slug predators, particularly carabid beetles and birds by landscape management and provision of overwinter stubbles		<u>Advantage</u>: reduces TFI, risk of pesticide leaching and entry in to water-courses <u>Advantage</u>: reduces TFI	-20% molluscicide -20% molluscicide -5% molluscicides

PIGEONS	**Crop: OSR**	If pigeons a severe problem, optimise sowing density/row width to provide a "closed canopy"		Disadvantages: High humidity from a "closed canopy" can increase disease risk The potential advantages of wide rows are lost	

AS

LANDSCAPE MANAGEMENT PRACTICES

Landscape management	**Practice**	**DEXiPM inputs**	**Observations**
INSECT PESTS			
Field margin	Provide non-crop refugia and resources for natural enemies: beetle banks, wild flower margins, grassy margins, hedges.		Maintain populations of natural enemies for crops by providing them with permanent habitats as sources alternative prey and as refugia from which to colonise cropped areas.
Crop areas	Maintain spatial and temporal diversity of cropping; Rotations including an entomophilous crop (e.g. WOSR); Inclusion of spring crops provides overwinter stubbles that support invertebrate predators		Crops are the largest part of arable landscapes. Crop type has more impact in determining invertebrate communities than does husbandry. Diverse cropping increases the diversity of resources offered to natural enemies and their spatial and temporal spread. Oilseed rape has a very diverse invertebrate community and is likely to be of value to many natural enemies as well as pollinators. There is insufficient knowledge to determine the optimal spatial or temporal arrangement of cropping for invertebrates, or to determine the optimal field size.
Non-crop areas	Maintain or create diversity of non-crop areas, e.g. woodland and game cover; Maintain or create high connectivity of non-crop habitats to facilitate movement of natural enemies.		Maintain diversity and abundance of natural enemies in the agricultural landscape. Maintain large-scale connectivity of meta-populations of natural enemies to ensure their survival and ability to move in the landscape in order to provide services in cropped areas.
DISEASES	No clear evidence for benefits from land management for diseases as yet.		
WEEDS	No clear evidence for benefits from land management for weeds as yet.		

Crop management practices for UK system AS

Crop management	Period (decade)	Practice and description	DEXiPM inputs (described in detail in the attached table)	Impact on pests	Disadvantages	Comments on pesticide reduction (see 'Crop protection strategy' table above for detailed listing of reductions by crop)
CROP SEQUENCE	5 years 4 years	I - winter wheat - spring beans (or other non-brassica dicot spring crop) - winter wheat - spring malting barley/spring milling wheat - winter oilseed rape II - winter wheat - spring beans (or other non-brassica dicot spring crop) - winter wheat - winter oilseed rape	No of crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover	Maximise potential to contain blackgrass and other pests by winter breaks with no crop. Diversification of crops reduces pest pressure and fosters diversity of natural enemies		TFI of current most common crop sequence (winter wheat, winter wheat, winter OSR) with current crop management practices : 6.2 (2006 data) Estimated TFI for AS crop sequences using current practices: I: representing a % reduction II: representing a % reduction
CROPS 1 and 3 in rotations I & II: WINTER WHEAT	Weeds: contain grass weeds, especially black grass Diseases: resistant variety, fungicide applied 2-3 timings (To, T1, T2, T3 as required). Insects: Minimising tillage, use of resistant cultivars, pesticide targeting and stewardship Potential pesticide reduction for this crop in relation to current practices: 17%					
Pre drilling tillage	Early September	Minimise cultivation	Superficial tillage between crops	Maintain soil inhabiting beneficials		
Drilling	Mid-late September	Criteria for variety choice ranked according to priority: 1) Bread-making quality, 2) yield, 3) Disease resistance rating primarily Septoria, 4) resistance to orange wheat blossom midge midge.	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level. Minimise midge damage.	Varieties not always available. The other criteria may compromise disease resistance	
		Sow mid September with insecticide-dressed seed. Avoid earlier sowing to reduce aphid risk.		Reduced incidence of Barley Yellow Dwarf Virus and reduced emergence of winter annual weeds	May increase slug problems on clay soils	The 30% TFI reduction potential associated with the use of (improved) seed dressings has probably already been realised.
Mechanical weeding		No	Superficial tillage in crops			
Mineral	Early April	No of operations: 1	Mineral P/K/S fertilizers			

Fertilization		Maintenance dressings in accordance with soil type.	applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 200 N for crop 1 and 180 N for crop 3	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		If necessary	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	August-September	Chemical weed control		Pre-drilling or pre-emergence herbicide		
	September to October	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Weed control, especially against grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and task prioritisation problems and lack of sufficient capacity Increased TFI Risk of resistance	Preceding oilseed rape or spring dicot crop maximises black grass containment.
	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of broad leaved weeds and any remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and task prioritisation problemsand lack of sufficient capacity Increased TFI Risk of resistance	
Fungicide	March-June	Chemical disease control, 2-3 treatments	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application	Control of Septoria Rust, mildew	Increased TFI, risk of resistance’	Field assessment should determine need. The TFI reduction potential associated with field assessment has already been realised as the optimised timing and dose is already in practise.

			Total number of treatment operations			
Insecticide	Mid September	Sow with insecticide-dressed seed		Control of aphids transmitting BYDV (e.g. *Sitobion avenae*)		
	Late October, early November	Chemical pest control required only if aphids active 6 weeks after drilling in a mild autumn because of use of treated seed and avoidance of sowing before mid September (see drilling above).		Control of aphids transmitting BYDV (e.g. *Sitobion avenae*)		Insecticide seed treatment (targeted on crop) often avoids need for less targetable insecticide spray.
	Mid October	In a warm autumn insecticide application in accordance with DSS advice		Control of aphids transmitting BYDV (e.g. *Sitobion avenae*)		
	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of aphids / orange wheat blossom midge (*Sitodiplosis mosellana*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Control of aphids according to field assessments and threshold. Control of midge according to monitoring thresholds on pheromone traps and counts on ears. Some midge-resistant varieties but not in bread-making wheats.
Growth regulator	April	Chemical control, Plant Growth Regulation	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Decreased risk of lodging	None	N-limitations, variety choice, seed rate and sowing date influence the need for PGR
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	End of August	Harvest with straw chopping and spreading.	Fuel consumption at harvest			

		Yield 8.0 t ha^{-1}				
CROP 2 in rotations I and II: SPRING BEANS	Introduction of spring crops and greater taxonomic diversity of crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Pests: breaking green bridge for cereal aphids, pesticide targeting and stewardship Diseases: breaking green bridge Potential pesticide reduction for this crop in relation to current practices: 24%					
Pre drilling tillage	February / March	Plough cultivation if necessary to create a seed-bed and for weed management	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	
Drilling	March – April	Criteria for variety choice ranked according to priority: 1) yield, 2) quality				
Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control slugs		
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide			

			application Total number of treatment operations			
Insecticide	April	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pea and bean weevil (*Sitona lineatus*) control		
	Late May, early June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Bruchid beetle and aphid control		
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield c. 5 t ha^{-1}	Fuel consumption at harvest			
CROP 3 in rotation I SPRING BARLEY	Introduction of spring crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Insects: breaking green bridge for cereal aphids , pesticide targeting and stewardship Diseases: breaking green bridge, resistant variety Potential pesticide reduction for this crop in relation to current practices: 28%					
Pre drilling tillage	March-April	Plough cultivation if necessary for weed management and to create a	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	

		seed-bed				
Drilling	March-April	Criteria for variety choice ranked according to priority: 1) yield, 2) malting quality, 3) leaf scald, 4) net-blotch.	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level	Varieties not always available. The other factors may compromise disease resistance	
	Density: 350-400 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	
Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 100 N	Mineral N fertilizer applications. Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide	leaf scald (*Rhynchosporium secalis*) , net-blotch, mildew.	Increased TFI, risk of resistance	Field assessment should determine need. The TFI reduction potential associated with field assessment has already been realised as the optimised timing and dose is already in practice.

			application Total number of treatment operations			
Insecticide	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of aphids	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Control of aphids according to field assessments and threshold.
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield 5.1 t ha^{-1}	Fuel consumption at harvest			
CROP 3 in rotation I SPRING WHEAT	Introduction of spring crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Insects: breaking green bridge for cereal aphids , pesticide targeting and stewardship Diseases: breaking green bridge, resistant variety Potential pesticide reduction for this crop in relation to current practices: 20%					
Pre drilling tillage	March-April	Plough cultivation if necessary for weed management and to create a seed-bed	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	
Drilling	March-April	Criteria for variety choice ranked according to priority: 1) bread-making quality, 2) yield, 3) take-all, 4) rust.	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level of take-all and rust.	Varieties not always available. The other factors may compromise disease resistance	
	Density: 350-400 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	

Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 140 N	Mineral N fertilizer applications. Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Rust, net-blotch, mildew.	Increased TFI, risk of resistance	Field assessment should determine need. The TFI reduction potential associated with field assessment has already been realised as the optimised timing and dose is already in practice.
Insecticide	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application	Control of orange wheat blossom midge (*Sitodiplosis mosellana*) and aphids	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Control of aphids according to field assessments and threshold. Control of midge according to monitoring thresholds on pheromone traps and counts on ears.

			Total number of treatment operations			
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield c. 5.5 t ha^{-1}	Fuel consumption at harvest			
CROP 4 in rotations I and II and Crop 3 in rotation III: WINTER OILSEED RAPE	Weeds: autumn/spring herbicide necessary Diseases: chemical control, resistant varieties, some DSS information available Insects: Minimising tillage before and after OSR, wide-rows (~50 cm), pesticide targeting and stewardship Reduced herbicide TFI Potential pesticide reduction for this crop in relation to current practices: 36%					
Drilling	mid-August	Criteria for variety choice ranked according to priority: 1) yield, 2) Disease resistance rating (Phoma, Light leaf spot), 3) seed price	Additional seed cost of cultivar, yield reduction due to cultivar		Good information on disease resistance from CEL recommended lists	
	mid-August	Minimise tillage, broadcast seed into cereal stubble or drill into wide-rows (~50 cm) behind subsoiler tines	Minimum tillage between crops			

	mid-August	Density: 25 - 50 plants m^{-1}	Sowing density			
	mid-August	Insecticide and fungicide seed dressing		Control flea beetles for 6 weeks		Reduced need for autumn insecticide spray
Mineral Fertilization	Mid March	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	Mid-September / Mid-March	No of operations: 1-2 Total amount kg ha^{-1}: 180 N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide	September-October	If necessary.	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			Depends on levels in field, assessed by scouting. Often requires more than one treatment
Herbicide	Pre-emergence (August-September)	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Grass weeds, mayweed, cleavers	Increased TFI Risk of resistance	Field assessment determines the need.
	Spring	Chemical weed control		Grass weed control according to need		
Fungicide	October - December	Chemical phoma control (against *Phoma lingam* in south of UK, *Pyrenopeziza brassicae* in north of UK), 1-2 treatments	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Phoma, Light leaf spot	Increased TFI, risk of resistance	
	April - May	Chemical disease control	TFI of fungicide	Sclerotinia stem rot	Increased TFI, risk of	Simple forecast system now available,

			Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	(*Sclerotinia sclerotium*)	resistance	reductions can be made during non-epidemic years (20 – 50% reduction)
Insecticide	September - December	Possible chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Adult cabbage stem flea beetle (*Psylliodes chrysocepthala*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	According to threshold (September to October: leaf damage or adults in water traps; November to December: larvae in plants)
	April (green to yellow bud stage)	Possible chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pollen beetle (*Meligethes aeneus*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Only if field threshold surpassed
	May	Possible chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Cabbage seed weevil, (*Ceutorhynchus assimilis*) & Brassica pod midge (*Dasineura brassicae*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance especially in pollen beetles	Only if field threshold surpassed
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor,		No	Total number of treatment operations			

pheromone…)						
Irrigation		No	Irrigation			
Harvest	Mid July	Harvest with straw chopping and spreading. GPS controlled combine Expected yield: 3.4 t ha^{-1}	Fuel consumption at harvest			Fuel savings

UK IS1-systems (differences from AS are written in bold)

Crop protection strategy: *principle components of the proposed IS1 according to the main pest risks identified in the current system*

Pest	Scale	Main crop protection tactics	Aim Impact on pests	Others impacts disadvantages & advantages	AS: Estimated % TFI change compared to an average farmer practicing the Current System (CS)	IS1: Estimated % TFI change compared to an average farmer practicing the Current System (CS)
WEEDS	**Cropping system**	Introduction of spring crops (**optionally increasing their proportion in the rotation**) and greater taxonomic diversity of crops **or fallow** for pest management, especially containment of black grass and other grass weeds. For spring crops, herbicide in March/April pre-drilling. **Consider fallow if grass weeds a severe problem and apply herbicide in March/April and July-September.**	Control of weeds: allows use of total herbicide in spring **and summer**; any inversion cultivation to create seed-bed for spring crop benefits grass weed (especially black grass) control and reduces weed seed bank.	Advantages: Spreading workload/flexibility Boost yield of following crop Potential value of overwinter stubbles, weeds and volunteers to invertebrates and birds prior to spring beans **and in fallow**. Spring crops yield less but gross margin is likely to be less affected due to premiums for milling wheat or malting barley, increased proportion of first wheats and better pest management. **No income from fallow but long term benefit for black grass control.**	See individual crops	See individual crops
		Minimise tillage and chop straw wherever possible. Before spring crops plough where necessary (in November for cereals, February/March for beans) to prepare for a spring seed-bed and/or for grass weed management especially blackgrass. O**ption of cultivation of fallow in May if grass weeds a severe problem.** Minimum tillage before oilseed rape with propyzamide application for black grass control.	Conserve soil-overwintering and epigeal invertebrate seed predators	Advantages: Less fuel/time Reduce CO_2 emissions Reduce wear of agricultural machinery Preserve soil structure, maintain moisture Conserve soil inhabiting natural enemies of all pests Decrease fertiliser use by increased nutrient cycling Reduce soil erosion and run-off Disadvantages: perennial weeds more difficult to control Some increased need for herbicides and molluscides likely.		
		Drilling OSR into wide-rows (~50 cm) to minimise necessary tillage,	Conserve soil-overwintering and epigeal invertebrate seed	**Advantages:** As for mimising tillage and **allows nutrient placement to**		See individual crops

		enable inter-row weed management (mechanical weeding where herbicide resistance is a problem, or targeted herbicide) and enable targeted applications of other pesticides and nutrients.	predators **Nutrient placement avoids fertilising weeds** **Mechanical weeding reduces herbicide resistance pressures**	**target crop plants and reduce leaching risk.** **Reduced pesticide TFI** **Disadvantage: high fuel and labour costs of mechanical weeding.**		
		Use higher seed rates and cultivars with strong competitiveness where weeds are problematic	Control weeds by competition	Advantages: Reduced costs & environmental impact Reduced resistance risk	See individual crops	See individual crops
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need	Effective pest control, reduce risk of resistance	Advantages: Reduced costs & environmental impact		No change (herbicide)
		Spot mapping and targeting of weeds	Target herbicide at weeds	Advantages: Reduced costs & environmental impact Reduced resistance risk		See individual crops
		GPS – controlled traffic system		**Advantages: Substantial fuel/herbicide savings Less soil compaction** **Less crop damage**		) -5% herbicide)))
		GPS – controlled pesticide applications		**Advantage: reduces TFI**		)
	Crop: winter wheat	Use higher seed rates and cultivars with strong competitiveness where weeds are problematic	Control weeds by competition	Advantages: Reduced costs & environmental impact Reduced resistance risk	-21% herbicide, +22% fungicide because closed canopy more humid	-21% herbicide TFI, +22% fungicide TFI because more dense crop is more humid
		Spot mapping and targeting of weeds		Advantages: Reduced costs & environmental impact Reduced resistance risk	-10% herbicide	-10% herbicide
	Crop: spring wheat	Use cultivars with strong competitiveness where weeds are problematic Plough in November if necessary to prepare for a spring seed-bed and for weed management but minimise	Control weeds by competition	Advantages: Reduced costs & environmental impact Reduced resistance risk	-33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid	-33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid

		tillage where possible. Spot mapping and targeting of weeds	 Target herbicide at weeds	 Advantages: Reduced costs & environmental impact Reduced resistance risk	 -15% herbicide	 -15% herbicide
	Crop: spring barley	Use higher seed rates and cultivars with strong competitiveness where weeds are problematic Plough in November if necessary to prepare for a spring seed-bed and for weed management but minimise tillage where possible. Spot mapping and targeting of weeds	Control weeds by competition Target herbicide at weeds	Advantages: Reduced costs & environmental impact Reduced resistance risk Advantages: Reduced costs & environmental impact Reduced resistance risk	33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid -15% herbicide	-33% herbicide TFI, +17% fungicide TFI because more competitive crop more dense & humid -15% herbicide
	Crop: Spring beans	Plough in February/March if necessary for weed management and to create a seed-bed but minimise tillage where possible. Spot mapping and targeting of weeds	 Target herbicide at weeds	Advantage: overwinter stubbles of value to invertebrates and birds Advantages: Reduced costs & environmental impact Reduced resistance risk	 -30% herbicide	 -30% herbicide
	Crop: Winter OSR	**Drilling into wide-rows (~50 cm)** to minimise necessary tillage, **enable inter-row weed management (mechanical weeding where herbicide resistance is a problem, or targeted herbicide using band-spraying) and enable targeted applications of insecticides and fungicides and nutrients.** Spot mapping and targeting of weeds **Nutrient placement**	 Target herbicide at weeds **Target nutrient at crop**	 **Advantage: reduce inorganic nutrient**	 -10% herbicide	-9% herbicide -10% herbicide

		Harvest WOSR after swathing **Use cultivars that are resistant to pod shattering and ripen evenly**	**plants and avoid fertilising weeds**	**input** Eliminates the need for a desiccant **<u>Advantage:</u> timing of harvest easier, less risk of seed loss, less likely to need desiccant**	-14% herbicide	-14% herbicide
	Crop: Fallow	**Chemical and if necessary mechanical control of competitive grass weeds, especially black grass: overwinter in stubble to allow weed seed germination; two total herbicides in March/April and July-September; option of possible cultivation in May if grass weeds severe; minimise tillage before following crop.** **Spot mapping and targeting of weeds**	**Target herbicide at weeds**	**<u>Disadvantages:</u> herbicides reduce potential value of fallow to invertebrate natural enemies and cultivation is detrimental to epigeal predators.**		-15% herbicide
INSECT PESTS	**Landscape**	Provide non-crop refugia and resources for natural enemies: field scale: beetle banks, wild flower margins, grassy margins, hedges. landscape scale: maintain spatial and temporal diversity of cropping; rotations including an entomophilous flowering crops (WOSR, S beans); diversity of non-crop areas, e.g. woodland, game cover; high connectivity of non-crop habitats to facilitate movement of natural enemies.	Maintain populations of natural enemies for crops by providing them with permanent habitats as sources alternative prey and as refugia from which to colonise cropped areas. Maintain diversity and abundance of natural enemies in the agricultural landscape. Maintain large-scale connectivity of meta-populations of natural enemies to ensure their survival and ability to move in the landscape in			-10% insecticide

			order to provide services in cropped areas.			
	Cropping system	Introduction of spring crops, greater taxonomic diversity of crops **and/or fallow** for pest management.	Break "green bridge" for pests. Diverse cropping increases the diversity of resources for natural enemies and their spatial and temporal spread.	Potential value over winter of stubbles, weeds and volunteers to invertebrates and birds	-5% insecticides	-5% insecticides
		Minimising tillage where possible.	Conserve soil-overwintering and epigeal natural enemies (invertebrates, and entomopathogens) of insect pests	<u>Advantage</u>: Reduced impact on natural enemies and environment, reduced TFI.	-10% insecticides	-10% insecticides
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.	Controlling insect pests according to economic thresholds Optimal timing of pest control	<u>Advantages:</u> Conserve invertebrate biodiversity including natural enemies & pollinators, reduced TFI, reduced risk of resistance	see individual crops (below)	see individual crops (below)
		GPS – controlled traffic system		**<u>Advantages</u>: Reduced costs, environmental impact and TFI**		) -5% insecticide))
		GPS – controlled pesticide applications		**<u>Advantages</u>: Substantial fuel/insecticide savings Less soil compaction Less crop damage**		))
	Crop: winter wheat	Minimising tillage especially before first wheat after OSR.	Conserves important soil-overwintering natural enemies, especially parasitoids of OSR pests.		see cropping system above	see cropping system above
		Use of resistant cultivars	Orange wheat blossom midge resistance **(all qualities of wheat)**		-12% insecticides	-25% insecticides
		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision			-10% insecticides	-10% insecticides

		support systems.				
	Crop: spring wheat	Plough if necessary for weed management and to create a seed-bed in spring (in autumn on heavy land) but minimise tillage where possible. **Use of resistant cultivars** Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.	 **Orange wheat blossom midge resistance**		see cropping system above -10% insecticides	see cropping system above -65% insecticides -10% insecticides
	Crop: spring barley	Plough if necessary for weed management and to create a seed-bed in spring (in autumn on heavy land) but minimise tillage where possible. Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems.			see cropping system above -50% insecticides	see cropping system above -50% insecticides
	Crop: Spring beans	Minimise tillage where possible. **Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need**		 **<u>Advantage</u>: reduces resistance risk**	see cropping system above	see cropping system above -45% insecticide
	Crop: Winter OSR	**Drilling into wide-rows (~50 cm)** to minimise necessary tillage, **and enable targeted applications of autumn insecticides.**	Minimum tillage after OSR conserves parasitoids of OSR pests as well as epigeal predators.	**<u>Advantage</u>: reduces TFI**	see cropping system above further -20% insecticide due to conservation of WOSR parasitoids	see cropping system above further -20% insecticide due to conservation of WOSR parasitoids

		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems. **Sow border trap crop for control of pollen beetles and other insect pests**	 **Reduce pest invasion of main crop**	 **<u>Advantage:</u> allow targeting of insecticides to trap crop only, reducing TFI and conserving beneficial insects.**	-75% insecticides	-75% insecticides -18% insecticides
	Crop: Fallow	**Breaking green bridge for cereal aphids.** **Minimise tillage: option of possible cultivation in May if grass weeds severe.**	 **Conserving generalist epigeal predators of pests, particularly carabid beetles and spiders, by provision of overwinter stubbles with undisturbed soil.**	 **<u>Advantage:</u> support overwintering bird populations by provision of overwinter stubbles**		

DISEASE	**Cropping system**	Introduction of spring crops (**optionally increasing their proportion in the rotation**) and greater taxonomic diversity of crops **or fallow** for pest management. Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, where possible using economic thresholds and decision support systems. **GPS – controlled traffic system** **GPS – controlled pesticide applications**	Break "green bridge" for diseases. Reduce inoculums carryover from season to season. Reduces TFI	Spring crops yield less but gross margin is likely to be less affected (see 'Weeds/cropping system' above) <u>Advantages</u>: reduced resistance risk **<u>Advantages</u>: Substantial fuel/fungicide savings Less soil compaction** **Less crop damage** **<u>Advantage</u>: reduces TFI**	-10% fungicides	-15% fungicides See individual crops below) -5% fungicides))))

	Crop: winter wheat	Use of more resistant cultivars		Advantage: reduces TFI, specifically reliance on “azole” fungicides Disadvantage: Some resistant cultivars yield less than non-resistant cultivars.	-10% fungicides	-20% fungicides
	Crop: spring wheat	Use of more resistant cultivars		Advantage: reduces TFI, specifically reliance on “azole” fungicides Disadvantage: Some resistant cultivars yield less that non-resistant	-10% fungicides	-20% fungicides
	Crop: spring barley	Use of more resistant cultivars		Advantage: reduces TFI, specifically reliance on “azole” fungicides Disadvantage: Some resistant cultivars yield less that non-resistant	-10% fungicides	-20% fungicides
	Crop: Spring beans	Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need		Advantage: reduces resistance risk	-10% fungicides	-10% fungicides
	Crop: Winter OSR	**Use of multi-resistant cultivars, especially for control of Phoma and light leaf spot.** Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems. **Targeting of autumn fungicides to plants in rows**	 **Targets fungicides onto pathogens on plants**	**Advantage: reduces TFI and reliance on limited chemistry** **Disadvantage: Some resistant cultivars don’t yield as highly as conventional.** Advantage: reduces resistance risk **Advantage: reduces TFI**	 -5% fungicides	- 50% fungicides -20% fungicides -30% fungicides
	Crop: Fallow	**Breaking green bridge for diseases**				
SLUGS	**Cropping System**	Where slugs are a severe problem, bale and cart straw and/or plough; roll twice after drilling.		Advantage: reduces TFI, risk of pesticide leaching and entry in to water-courses	-20% molluscicide	-20% molluscicide

		Pesticide targeting and stewardship: ensure effective use of pesticides strictly according to need, using economic thresholds and decision support systems. **GPS – controlled traffic system** Conserving slug predators, particularly carabid beetles and birds by landscape management and provision of overwinter stubbles **and fallow fields**.		<u>Advantage</u>: reduces TFI **<u>Advantages</u>: Substantial fuel/molluscicide savings. Reduces TFI. Less soil compaction. Less crop damage**	-20% molluscicide -5% molluscicides	-20% molluscicide -3% molluscicide -5% molluscicides (-10% molluscides in rotations with fallow)
PIGEONS	**Crops: OSR**	If pigeons a severe problem, optimise sowing density/row width to provide a "closed canopy"		<u>Disadvantages</u>: High humidity from a "closed canopy" can increase disease risk The potential advantages of wide rows are lost		

IS1

LANDSCAPE MANAGEMENT PRACTICES for UK system IS1 (Changes from AS in bold)

Landscape management	Practice	DEXiPM inputs	Observations
INSECT PESTS			
Field margin	Provide non-crop refugia and resources for natural enemies: beetle banks, wild flower margins, grassy margins, hedges. **Contour beetle banks on sloping fields to control soil erosion** **Trap crop of early-flowering brassica around edge of WOSR crop**		Maintain populations of natural enemies for crops by providing them with permanent habitats as sources of alternative prey and as refugia from which to colonise cropped areas. **Dual role for beetle banks** **To concentrate pests, particularly pollen beetles, at the edge of the crop and protect the main crop from pollen beetle immigration at the vulnerable green-yellow bud stage. To enable any necessary insecticide treatment to be spatially targeted to the crop margin, reducing TFI and non-target impacts.**
Crop areas	Maintain spatial and temporal diversity of cropping; Rotations including an entomophilous crop (e.g. WOSR);		Crops are the largest part of arable landscapes. Crop type has more impact in determining invertebrate communities than does husbandry. Diverse cropping increases the diversity of resources offered to natural enemies and their spatial and temporal spread. Oilseed rape has a very diverse invertebrate community and is likely to be of value to many natural enemies as well as pollinators. There is insufficient knowledge to determine the optimal spatial or temporal arrangement of cropping for invertebrates, or to determine the optimal field size.
Non-crop areas	Maintain or create diversity of non-crop areas, e.g. woodland and game cover; Maintain or create high connectivity of non-crop habitats to facilitate movement of natural enemies.		Maintain diversity and abundance of natural enemies in the agricultural landscape. Maintain large-scale connectivity of meta-populations of natural enemies to ensure their survival and ability to move in the landscape in order to provide services in cropped areas.
DISEASES	No clear evidence for benefits from land management for diseases as yet.		
WEEDS	No clear evidence for benefits from land management for weeds as yet.		

Crop management practices for UK system IS1 (Changes from AS in bold)

Crop management	Period (decade)	Practice and description	DEXiPM inputs (described in detail in the attached table)	Impact on pests	Disadvantages	Comments on pesticide reduction (see 'Crop protection strategy' table above for detailed listing of reductions by crop)
CROP SEQUENCE	5 years 4 years	III - winter wheat - spring beans (or other non-brassica dicot spring crop) - winter wheat - spring malting barley/spring milling wheat/fallow - winter oilseed rape IV - winter wheat - spring beans (or other non-brassica dicot spring crop) - spring malting barley/spring milling wheat / fallow - winter oilseed rape	No of crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover	Maximise potential to contain blackgrass and other pests by winter breaks with no crop **or annual fallow**. Diversification of crops reduces pest pressure and fosters diversity of natural enemies		TFI of current most common crop sequence (winter wheat, winter wheat, winter OSR) with current crop management practices : 6.2 (2006 data) Estimated TFI for IS1 crop sequences using current practices: III: representing a % reduction IV: representing a % reduction
CROPS 1 and 3 in rotation III CROP 1 in rotation IV WINTER WHEAT	Weeds: contain grass weeds, especially black grass Diseases: resistant variety, fungicide applied 2-3 timings (To, T1, T2, T3 as required). Insects: Minimising tillage, use of resistant cultivars, pesticide targeting and stewardship Potential pesticide reduction for this crop in relation to current practices: 27%					
Pre drilling tillage	Early September	Minimise cultivation	Superficial tillage between crops	Maintain soil inhabiting beneficials		
Drilling	Mid-late September	Criteria for variety choice ranked according to priority: 1) Bread-making quality, 2) yield, 3) Disease resistance rating primarily Septoria, 4) resistance to orange wheat blossom midge midge.	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level. Minimise midge damage.	Varieties not always available. The other criteria may compromise disease resistance	
		Sow mid September with insecticide-dressed seed. Avoid earlier sowing to reduce aphid risk.		Reduced incidence of Barley Yellow Dwarf Virus and reduced emergence of winter	May increase slug problems on clay soils	The 30% TFI reduction potential associated with the use of (improved) seed dressings has probably already been realised.

				annual weeds		
Mechanical weeding		No	Superficial tillage in crops			
Mineral Fertilization	Early April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	Early April	No of operations: 1 Total amount kg ha^{-1}: 200 N for crop 1 and 180 N for crop 3	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		no	Organic N fertilizer applications, Total number of treatment operations			
Molluscicide		If necessary	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	August-September	Chemical weed control		Pre-drilling or pre-emergence herbicide		
	September to October	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Weed control, especially against grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and task prioritisation problems and lack of sufficient capacity Increased TFI Risk of resistance	Preceding oilseed rape or spring dicot crop maximises black grass containment.
	April	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of broad leaved weeds and any remaining grass weeds	Optimal timing can be jeopardized by unfavourable weather conditions and task prioritisation problemsand lack of sufficient capacity Increased TFI Risk of resistance	
Fungicide	March-June	Chemical disease control, 2-3 treatments	TFI of fungicide Total pesticide TFI	Control of Septoria Rust, mildew	Increased TFI, risk of resistance	Field assessment should determine need. The TFI reduction potential associated

			Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			with field assessment has already been realised as the optimised timing and dose is already in practise
Insecticide	Mid September	Sow with insecticide-dressed seed		Control of aphids transmitting BYDV (e.g. *Sitobion avenae*)		
	Early October	Chemical pest control required only if aphids active 6 weeks after drilling in a mild autumn because of use of treated seed and avoidance of sowing before mid September (see drilling above).		Control of aphids transmitting BYDV (e.g. *Sitobion avenae*)		Insecticide seed treatment (targeted on crop) often avoids need for less targetable insecticide spray.
	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of aphids / orange wheat blossom midge (*Sitodiplosis mosellana*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Control of aphids according to forecasts and field assessments. Control of midge according to monitoring thresholds on pheromone traps and counts on ears. Midge-resistant wheat varieties.
Growth regulator	April	Chemical control, Plant Growth Regulation	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Decreased risk of lodging	None	N-limitations, variety choice, seed rate and sowing date influence the need for PGR
Other chemical product		No				
Biological control product (elicitor, pheromone..)		No				
Irrigation		No				
Harvest	End of	Harvest with straw chopping and	Fuel consumption at harvest			

	August	spreading. Yield 8.0 t ha^{-1}				
CROP 2 in rotations I and II: SPRING BEANS	Introduction of spring crops and greater taxonomic diversity of crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Pests: breaking green bridge for cereal aphids, pesticide targeting and stewardship Diseases: breaking green bridge Potential pesticide reduction for this crop in relation to current practices: 41%					
Pre drilling tillage	February / March	Plough cultivation if necessary to create a seed-bed and for weed management	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	
Drilling	March – April	Criteria for variety choice ranked according to priority: 1) yield, 2) quality				
Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control slugs		
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity			

			Soil cover at pesticide application Total number of treatment operations			
Insecticide	April	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pea and bean weevil (*Sitona lineatus*) control		Field assessment, spraying according to need
	Late May, early June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Bruchid beetle and aphid control		Field assessment, spraying according to need
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone..)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield c. 5 t ha^{-1}	Fuel consumption at harvest			
OPTIONAL crop 4 in rotation III or crop 3 in rotation IV SPRING	Introduction of spring crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Insects: breaking green bridge for cereal aphids , pesticide targeting and stewardship Diseases: breaking green bridge, resistant variety Potential pesticide reduction for this crop in relation to current practices: 37%					

BARLEY						
Pre drilling tillage	March-April	Plough cultivation if necessary for weed management and to create a seed-bed	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	
Drilling	March-April	Criteria for variety choice ranked according to priority: 1) yield, 2) malting quality, 3) leaf scald, 4) net-blotch.	Additional seed cost of cultivar, yield reduction due to cultivar	Reduced disease level	Varieties not always available. The other factors may compromise disease resistance	
	Density: 350-400 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	
Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 100 N	Mineral N fertilizer applications. Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI	leaf scald (*Rhynchosporium*	Increased TFI, risk of resistance	Field assessment should determine need. The TFI reduction potential associated

			Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	*secalis*) , net-blotch, mildew.		with field assessment has already been realised as the optimised timing and dose is already in practice.
Insecticide	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of aphids	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Control of aphids according to field assessments and threshold.
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone..)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield 5.1 t ha^{-1}	Fuel consumption at harvest			
OPTIONAL crop 4 in rotation III or crop 3 in rotation IV SPRING WHEAT	Introduction of spring crops to reduce pest pressure and foster diversity of natural enemies. Weeds: Maximises possibilities for containment of grass weeds, particularly black grass. Insects: breaking green bridge for cereal aphids , pesticide targeting and stewardship Diseases: breaking green bridge, resistant variety Potential pesticide reduction for this crop in relation to current practices: 33%					
Pre drilling tillage	March-April	Plough cultivation if necessary for weed management and to create a seed-bed	Plough	Buries weed seed, helps control slugs	Bad for soil-inhabiting beneficials	
Drilling	March-April	Criteria for variety choice ranked according to priority: 1) bread-	Additional seed cost of cultivar, yield reduction due to	Reduced disease level of take-all and rust.	Varieties not always available. The other factors may	

		making quality, 2) yield, 3) take-all, 4) rust, 5) orange wheat blossom midge.	cultivar	Minimise midge damage.	compromise disease resistance	
	Density: 350-400 pl. m^{-2}	Sowing density	Additional seed cost of cultivar, yield reduction due to cultivar	Improved crop competiveness against weeds	Lodging	
Mechanical weeding		No				
Mineral Fertilization	March-April	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	March-April	No of operations: 1 Total amount kg ha^{-1}: 140 N	Mineral N fertilizer applications. Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		If necessary (unlikely)	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	February-April	Pre-tillage or pre-emergence chemical weed control (glyphosate)	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	control weeds		
Fungicide	May-June	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity	Rust, net-blotch, mildew.	Increased TFI, risk of resistance	Field assessment should determine need. The TFI reduction potential associated with field assessment has already been realised as the optimised timing and dose is

			Soil cover at pesticide application Total number of treatment operations			already in practice.
Insecticide	May-June	Chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Control of aphids.	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Resistant varieties against orange wheat blossom midge Control of aphids according to field assessments and threshold.
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone..)		No				
Irrigation		No				
Harvest	Mid-August	Harvest with straw chopping and spreading. Yield c. 5.5 t ha^{-1}	Fuel consumption at harvest			
OPTIONAL crop 4 in rotation III, crop 3 in rotation IV: FALLOW	Weeds: Maximises possibilities for containment of grass weeds, particularly black grass Pests: breaking green bridge for cereal aphids Diseases: breaking green bridge Nutrition: application of micro-nutrients using sewage sludge or chicken manure Potential pesticide reduction in relation to current practices: 15%					
Herbicide	March/ April and June/July	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Weed control, especially against grass weeds		

Cultivation	May	Inversion cultivation if grass weeds are a problem	Tillage type (inversion) Total number of treatment operations	Weed control, especially against grass weeds		
CROP 4 in rotations I and II and Crop 3 in rotation III: WINTER OILSEED RAPE	Weeds: autumn/spring herbicide necessary, possibilities for mechanical weeding, Diseases: chemical control, resistant varieties, some DSS information available Insects: Minimising tillage before and after OSR, wide-rows (~50 cm), pesticide targeting and stewardship, **trap cropping** Reduced herbicide TFI Potential pesticide reduction for this crop in relation to current practices: 59%					
Drilling	mid-August	Criteria for variety choice ranked according to priority: 1) yield, 2) Disease resistance rating (Phoma, Light leaf spot), 3) seed price	Additional seed cost of cultivar, yield reduction due to cultivar		Good information on disease resistance from CEL recommended lists	
	mid-August	Drill into wide-rows (~50 cm) behind subsoiler tines to enable mechanical weeding, targeted pesticides and nutrient placement	Minimum tillage between crops			
	mid-August	Density: 25 - 50 plants m^{-1}	Sowing density			
	mid-August	Insecticide and fungicide seed dressing		Control flea beetles for 6 weeks		Reduced need for autumn insecticide spray
Inter-row weed management	**Mid-September**	**Inter-row weed management (mechanical weeding where herbicide resistance is a problem, or targeted herbicide using band-spraying)**	**Superficial tillage in crops**	**Weed control in general. May reduce slug incidence**	**Availability of machinery, low capacity, weather dependency. Insufficient effect against high levels of volunteers and grass weeds in the rows**	
Mineral Fertilization	Mid March	No of operations: 1 Maintenance dressings in accordance with soil type.	Mineral P/K/S fertilizers applications Total number of treatment operations			
	Mid-September / Mid-March	No of operations: 1-2 Total amount kg ha^{-1}: 180 N	Mineral N fertilizer applications Total number of treatment operations			
Organic		No	Organic N fertilizer			

Fertilization			applications Total number of treatment operations			
Molluscicide	September-October	If necessary.	Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			Depends on levels in field, assessed by scouting. Often requires more than one treatment
Herbicide	Pre-emergence (August-September)	Chemical weed control	TFI of herbicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Grass weeds, mayweed, cleavers	Increased TFI Risk of resistance	Field assessment determines the need.
	Spring	Chemical weed control		Grass weed control according to need		
Fungicide	October - December	Chemical phoma control (against *Phoma lingam* in south of UK, *Pyrenopeziza brassicae* in north of UK), 1-2 treatments	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Phoma, Light leaf spot	Increased TFI, risk of resistance	
	April - May	Chemical disease control	TFI of fungicide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Sclerotinia stem rot (*Sclerotinia sclerotium*)	Increased TFI, risk of resistance	Simple forecast system now available, reductions can be made during non-epidemic years (20 – 50% reduction)
Insecticide	September - December	Possible chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide	Adult cabbage stem flea beetle (*Psylliodes chrysocepthala*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	According to threshold (September to October: leaf damage or adults in water traps; November to December: larvae in plants)

			application Total number of treatment operations			
	April (green to yellow bud stage)	Possible chemical pest control **To trap crop only**	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Pollen beetle (*Meligethes aeneus*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance	Only if field threshold surpassed **If trap crop is 10% of crop area, insecticide use is reduced by 90%**
	May	Possible chemical pest control	TFI of insecticide Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Cabbage seed weevil, (*Ceutorhynchus assimilis*) & Brassica pod midge (*Dasineura brassicae*)	Increased TFI, risk of non-target effects on beneficial insects, risk of resistance especially in pollen beetles	Only if field threshold surpassed
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone..)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Mid July	Harvest with straw chopping and spreading. GPS controlled combine Expected yield: 3.4 t ha^{-1}	Fuel consumption at harvest			Fuel savings

France AS systems

Principles: *principles of the AS/IS are proposed regarding the main pest risk identified in the current system*

Pest	Scale	Main crop protection strategies, main principles	Aim Impact on pests (weeds, diseases, insect pests)	Others impacts disadvantages & advantages
WEEDS	**Cropping system**	Diversifying sowing periods by introducing spring crops and shifting sowing dates (early/late sowing dates)	Non-specialized weed flora: to reduce autumn weed seedbank To allow false seedbed between harvest and drilling (late sowing or spring crops)	☹Risk to increase spring weeds seedbank ☹Energy and time cost (false seedbed) ☺Positive impact on diseases (sowing dates) ☺Work organisation may be improved
		Systematic intermediate catch crop when spring crops	Competitiveness against Autumn weeds	☺Decrease NO3 leaching when spring crops ☺Less nitrogen application to next crop
		Superficial tillage in and between crops/deep tillage when necessary	To reduce weeds	☹Energy and time cost ☺Soil biodiversity (less deep tillage)
	Crop: WOSR	Double row spacing	To allow mechanical weeding	☹Energy and time cost (mechanical weeding)
	Crop: winter wheat	Diversifying sowing periods: late sowing date (only one wheat of the crop sequence because of organisation problem)	False seedbed To reduce autumn weeds seedbank	☺Also efficient to decrease susceptibility to diseases, slugs and aphids causing BYD (no autumn insecticide against aphids, less fungicide) ☹Energy and time cost ☹Risk of lower yield ☹Risk of unsuitable sowing conditions
	Crop: spring barley	Diversifying sowing periods: late sowing date	False seedbed To reduce autumn weeds seedbank	☺Also efficient to decrease susceptibility to diseases, slugs and aphids causing BYD (no autumn insecticide against aphids, less fungicide) ☹Energy and time cost ☹Risk of lower yield ☹Risk of unsuitable sowing conditions
INSECTS PESTS	**Crop: WOSR**	Mixture with 10% early cultivars	To limit pollen beetles (trapped by early cultivar)	
	Crop: Winter wheat	Late sowing date (only one wheat of the crop sequence because of organisation problem)	To reduce insects in Autumn	☺Also efficient to decrease susceptibility to diseases, slugs ☹Risk of lower yield ☹Risk of unsuitable sowing conditions
		Autumn insecticides against aphids if problems (1/5 year for late sowing, 4/5 for usual sowing date)	To limit aphids and yellow dwarf	
DISEASE	**Cropping system**	Diversifying crops in the rotation	Increase duration between the same crop	☹Lower frequency of cash crops
		Use of resistant cultivars against disease with various earliness, cultivar mixture		☹Resistant cultivars sometimes less productive ☹Delivery constraints with cultivar mixture

SLUGS	**Crops**	Chop and burry straws	To destroy slug eggs	☺Increase of soil organic matter ☹Energy and time cost

<u>AS prototype</u>

LANDSCAPE MANAGEMENT PRACTICES

None

CROP MANAGEMENT PRACTICES

Crop management	Period (decade)	Practice and description	DEXiPM inputs (described in detail in the attached table)	Effect on pests (weeds, diseases, insect pests)	Observations / disadvantages	Pesticide reduction
CROP SEQUENCE		**Winter oilseed rape-winter wheat-winter barley-(intermediate legumes)-sunflower-winter wheat**	**Nb of crops, proportion of summer crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover**			
Pre-drilling tillage	Early august (just after harvest of preceding crop)	Stubble breaking (cover crop) + rolling *(roulage)* Nb of operations: 2	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
	End of august	Stale seedbed (vibro) Nb of operations: 1	Superficial tillage between crops	Destruction of seedling: less favourable to slugs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide Less molluscicide (on margin)
		Deep tillage: no	Deep tillage	Preserve soil natural enemies		
		Inversion tillage: no	Tillage type (inversion)	Preserve soil natural enemies		
CROP 1: winter oilseed rape	**Weeds**: double row spacing to allow mechanical weeding **Diseases**: resistant cultivars (against phoma), chemical control against sclerotinia **Insects pests**: early cultivars (10%, mixture) to trap pollen beetle, insecticides against other insects					
Drilling	Early September	Cultivar: resistant against phoma, earliness: cultivar mixture with 10% early cultivars Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar	10% early cultivars to trap pollen beetles	☹Yield loss risk due to cultivar	No insecticide against pollen beetle
		Combined tool (Seeder+superficial tool) + roll Nb of operations: 2 (count 3 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 40 pl /m² (row spacing 45cm)	Sowing density		Wide row spacing for mechanical weeding	Reduction of herbicide (mechanical weeding because large row spacing)
Mechanical weeding	Autumn	2 hoeing *(binage)* Nb of operations: 2	Superficial tillage in crops	Decrease autumn weeds	☹Energy and time cost	Reduction of herbicide
	Spring	1 hoeing *(binage)* Nb of operations: 1	Superficial tillage in crops	Decrease autumn weeds	☹Energy and time cost	Reduction of herbicide

Mineral Fertilization	August	Nb of operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 100 P, 150 K	Mineral P/K fertilizers applications Total number of treatment operations			
	Beginning of February	Nb of operations: 1 Total amount (in kg/ha): 70N	Mineral N fertilizer applications Total number of treatment operations			
	Beginning of march	Nb operations: 1 75S	Total number of treatment operations			
	Beginning of march	Nb operations: 1 Total amount (in kg/ha): 80N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide	End of August (emergence)	Metaldehyde (field margin) TFI 0.3	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations	Stubble breaking efficient against slugs		Reduction of molluscicide
Herbicide	Early September (post-sowing)	Novall (TFI 0.33, on row) + kerb (TFI 0.33, on row) Total TFI 0.66		Against mono and dicotyledonous	Mechanical weeding (no treatment between rows)	Reduction of herbicide (mechanical weeding)
Fungicide	Spring	Against sclerotinia (TFI 0.75)		Against sclerotinia	Resistant cultivar (no treatment against phoma)	
Insecticide	Spring	Insecticide against stem weevils TFI 1 Insecticide (1/2 year) against cabbage stem flee beetles (*Altises*) TFI 0,5 Insecticide against pod weevils and/or aphids TFI 1		against stem weevils, cabbage stem flee beetles, pod weevils, aphids	No treatment against pollen beetles (cultivar mixture)	Reduction of insecticide
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No	Total number of treatment operations			
Irrigation		No	Irrigation			
Harvest	Beginning of	Operation: classic (no additional cost)	Fuel consumption at harvest			

	July	Expected yield: 27 qx/ha (range: 25-34)				
POST-HARVEST MANAGEMENT/ pre drilling tillage	Beginning July (after harvest)	Stubble breaking (cover crop) Nb of operations: 1	Superficial tillage between crops	Enhance emergence of volunteers	☺Less risk of nitrate leaching	
	Mid- September	Stale seedbed (cover crop and vibro) Nb of operations : 2	Superficial tillage between crops	Destruction of seedling (weeds and volunteers): less favourable to slugs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide No molluscicide
Intermediate crop		No (but WOSR volunteers favoured)				
CROP 2: winter wheat	**Weeds**: mechanical weeding, spring herbicide **Diseases**: cultivar mixture with resistant cultivars, low N fertilization **Insects**: insecticides Autumn **Lodging**: low N fertilization					
Drilling	Mid-Octobre	Cultivar: cultivar mixture (resistant against septoria) Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar	Resistance against septoria	☹Yield loss risk due to cultivar	Reduction of fungicide
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 300 pl /m²	Sowing density			
Mechanical weeding	Autumn	2 harrowing (*herse etrille*) Nb of operations: 2	Superficial tillage in crops		☹Energy and time cost ☹Risk of non-suitable weather conditions	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 80N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator Less fungicide
	Mid April	Nb of operations: 1 Total amount: 50N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator Less fungicide
		No P-K (see WOSR)				
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide			
Herbicide	Beginning of March	Allié TFI 0.75		Against mono and dicotyledonous	Mechanical weeding (less treatment)	Reduction of herbicide
Fungicide	April	Fungicide against foliar disease TFI 1			Cultivar, low N fertilization	Reduction of fungicide

Insecticide	Autumn	Insecticide against aphids (3/5 year) TFI 0.6	application Total number of treatment operations			
	Spring	Insecticide against aphids (1/5 year) TFI 0.2				
Growth regulator		No			Low N fertilization, low sowing density	No regulator
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No	Irrigation			
Harvest	Mid July	Operation: classic (no additional cost) Expected yield: 65q/ha (range 50-69)	Fuel consumption at harvest			
		Straws buried	Stubble management	Avoid slugs	☺Soil organic matter	Less molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	July (at harvest of wheat)	Stubble breaking (covercrop)+rolling Nb of operations: 2	Superficial tillage between crops			
	From August to November	Stale seedbed (vibro) Nb of operations : 2	Superficial tillage between crops	Decrease autumn weeds seedbank and slug eggs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide and molluscicide
Intermediate crop		No				
CROP 3: winter barley	**Weeds**: late sowing to allow false seedbed mechanical weeding, herbicide **Diseases**: low N fertilization, resistant cultivar, low density, late sowing **Lodging**: low N fertilization					
Drilling	Beginning of November	Cultivar: resistant against leaf stripe, dwarf leaf rust (*puccinia*) Treated seeds against yellow dwarf virus	Additional seed cost of cultivar, yield reduction due to cultivar	Limit diseases and limit risk of aphids	☹Yield loss risk due to cultivar and late sowing	Reduction of fungicides
		Combined tool (seeder+superficial tool) Nb of operation: 1(count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing limit risk of aphids and diseases		
		Density: 250 pl /m²	Sowing density	Limit diseases	☺Limit lodging	Reduction of fungicide and no growth regulator
Mechanical weeding	Beginning of March	1 harrowing (*herse etrille*)	Superficial tillage in crops	Limit weeds	☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	End of February	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment	Low N fertilization to limit disease risk	☺Low N fertilization to	No growth regulator

			operations		limit lodging risk	
	End of March	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N fertilization to limit disease risk	☺Low N fertilization to limit lodging risk	No growth regulator
Organic Fertilization		No				
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	end of march	Bofix (against dicotyledonous, TFI 0.5)+herbicide against wild oat (TFI 0.5) TFI 1				
Fungicide	Spring	Against aerial diseases TFI 0.75			Cultivar, low N fertilization, sowing date, density	
Insecticide		No (seed treatment)			Sowing date, seed treatment	
Growth regulator		No			Low N fertilization, low density	
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Mid-July	Operation: classic (no additional cost) Yield 65 q/ha (range 50-70)	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	Mid-July (at harvest)	Stubble breaking (covercrop)+rolling Nb of operations: 2	Superficial tillage between crops			
	August	Stale seedbed (lemken) Nb of operations : 1	Superficial tillage between crops		☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide
Intermediate crop	Mid August	Catch crop (mixture of legumes, resistant to frost)	Number of crops	Effect on weeds (competitiveness)	☺Nitrogen application for next crop, positive effect on soil structure, decrease of leaching risk	

					during winter period	
	Mid-February	Chopping (*broyage*) or rolling	Superficial tillage between crops			
	Mid-February	Deep tillage (inversion) + superficial tillage (vibro)	Deep tillage, inversion tillage, Superficial tillage between crops		☹Energy and time cost	
CROP 4: sunflower	**Weeds**: mechanical weeding **Diseases**: resistant cultivar					
Drilling	Mid-April	Cultivar: multi-resistant Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar	
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 7 pl /m²	Sowing density			
Mechanical weeding	May-June	3 hoeing (*binage*) Nb of operations: 3	Superficial tillage in crops		☹Energy and time cost	No herbicide between rows
Mineral Fertilization	End of April	Nb of operations : 1 Total amount: 100P, 100K	Mineral P/K fertilizer applications Total number of treatment operations		Restitution of N by intermediate catch crop	
Organic Fertilization		No				
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide		Novall on row (*Ammi majus*) TFI 0.33				
Fungicide		No			Resistant cultivar	
Insecticide		No				
Growth regulator		No on sunflower				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	End September	Operation: classic (no additional cost) Expected yield 23q/ha (range: 15-23)	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of September	Chopping (*broyage*) Nb of operations: 1	Superficial tillage between crops	Limit weeds, destruction of seedlings (slugs)		Reduction of herbicide Less molluscicide
	End of September	Stubble cultivation (covercrop) +rolling	Superficial tillage between crops	Limit weeds, destruction of		Reduction of herbicide Less molluscicide

		Nb of operations: 2		seedlings (slugs)		
	Mid-October	False seedbed (vibro)+rolling Nb of operations: 2	Superficial tillage between crops	Limit weeds, destruction of seedlings (slugs)		Reduction of herbicide Less molluscicide
CROP 5: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide **Diseases**: late sowing, resistant hardy cultivars, low N fertilization, low density **Insects**: late sowing (autumn aphids), insecticides 1/5 year **Lodging**: late sowing, low N fertilization, low density **Slugs**: late sowing					
Drilling	Early November	Cultivar: hardy Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar and late sowing	No fungicide
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility and allow more false seedbed		Reduction of herbicide
		Density: 250 pl /m²	Sowing density			
Mechanical weeding	Mid-february	1 harrowing (*herse etrille*) (1/2 year) Nb of operations: 1/2	Superficial tillage in crops	Limit weeds	☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 80N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator Less fungicide
	Mid April	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator Less fungicide
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Late sowing	
Herbicide	May	Against dicot and monocotyledonous TFI 0.75 Nb of operations: 1				Reduction of herbicide
Fungicide	April	Fungicide against foliar disease TFI 0.5 Nb of operations: 1			Cultivar, low N fertilization, low sowing density	Reduction of fungicide
Insecticide	Spring	Insecticide against aphids (1/5 year) TFI 0.2 Nb of operations: 1				
Growth regulator		No			Late sowing, low	

					N fertilization, low sowing density	
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		no				
Harvest	Mid-July	Operation: classic (no additional cost) Expected yield 60q (range 50-65)	Fuel consumption at harvest		Late sowing: lower expected yield than first wheat	
		Straws chopped and buried	Stubble management	Avoid slugs		Less molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	Early august (just after harvest)	Stubble breaking (cover crop) + rolling *(roulage)* Nb of operations: 2	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
	End of august	Stale seedbed (vibro) Nb of operations: 1	Superficial tillage between crops	Destruction of seedling: less favourable to slugs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide No molluscicide

France Innovative system

Principles: *principles of the AS/IS are proposed regarding the main pest risk identified in the current system*

Pest	Scale	Main crop protection strategies, main principles	Aim Impact on pests (weeds, diseases, insect pests)	Others impacts disadvantages & advantages
WEEDS	**Cropping system**	Extending and diversifying crop rotation (competitive crop)	To increase competitiveness against spring weeds	
		Diversifying sowing periods by shifting sowing dates (early/late sowing dates)		☹Energy and time cost (false seedbed) ☺Positive impact on diseases (sowing dates) ☹Risk of yield loss
		False seedbed (except when mustard)	To reduce weeds	☹Energy and time cost
		Systematic intermediate catch crop when spring crops	Competitiveness against Autumn weeds	☺Decrease NO3 leaching when spring crops ☺Reduce nitrogen application to next crop ☹Risk to increase slugs depending on the catch crop used
		Odd number of deep tillage between two successive cereals	To reduce weeds	☺Positive impact to decrease eyespot of wheat
	Crop: WOSR	Diversifying sowing periods: early sowing date	To increase competition against weeds	☺Also efficient to decrease susceptibility to phoma, slugs and autumn insects (*e.g.* weevils): less fungicide and insecticide ☹Might be lodging problems as no growth regulator
	Crop: winter wheat	Diversifying sowing periods: late sowing date	False seedbed To reduce autumn weeds seedbank	☺Also efficient to decrease susceptibility to diseases, slugs and aphids causing BYD (no autumn insecticide against aphids, less fungicide) ☹Energy and time cost ☹Risk of lower yield ☹Risk of unsuitable sowing conditions
	Crop: sugarbeet	Mechanical weeding, herbicide on row	To reduce weeds	☹Energy and time cost
INSECTS PESTS	**Crop: WOSR**	Mixture with 10% early cultivars	To limit pollen beetles (trapped) Reduce TFI	☹Risk of lower yield
	Crop: Winter wheat	Late sowing date	To reduce Autumn treatment	☹Risk of lower yield ☺Reduce disease and lodging
		Insecticides against aphids if problems (1/5 year for late sowing)	To limit aphids and BYD	
DISEASE	**Cropping system**	Use of resistant cultivars against disease with various earliness, cultivar mixture		☹Resistant cultivars sometimes less productive ☹Delivery constraints with cultivar mixture
SLUGS	**Crops**	Chop and burry straws		☺Increase of soil organic matter

IS prototype

LANDSCAPE MANAGEMENT PRACTICES

None

CROP MANAGEMENT PRACTICES

Crop management	Period (decade)	Practice and description	DEXiPM inputs (described in detail in the attached table)	Effect on pests (weeds, diseases, insect pests)	Observations / disadvantages	Pesticide reduction
CROP SEQUENCE		**(Mustard)-Sugarbeet-winter wheat-(Mustard)-hemp-winter wheat-winter oilseed rape-winter wheat**	**Nb of crops, proportion of summer crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover**			
Pre-drilling tillage	Early august (just after harvest of preceding crop)	Stubble breaking (cover crop) + rolling *(roulage)* Nb of operations: 2	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
Intermediate catch crop	Beginning of August	Mustard 12kg/ha				
		Broadcast sowing + harrowing + rolling Nb of operations: 3	Superficial tillage between crops			
	February	Mechanical breaking (if not killed by frost) Nb of operations: 1	Superficial tillage between crops		☺Less risk of nitrate leaching	Reduction of herbicide (No glyphosate)
	End of February	Ploughing (Inversion tillage)	Deep tillage, Tillage type (inversion)	Reduce weeds	☹Energy and time cost	Reduction of herbicide
CROP 1: sugarbeet	**Weeds**: no specialisation of flora and less problems with weeds in sugarbeet by introduction of hemp (competitiveness): **Diseases**: resistant cultivars, low N fertilization					
Drilling	Beginning of march	Cultivar: resistant Treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar	Reduce insecticide
		Combined tool (Seeder+superficial tool) + roll Nb of operations: 2 (count 3 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 13 pl /m²	Sowing density			
Mechanical weeding	Spring	1 hoeing (*houe*) Nb of operations: 1	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
	Spring	1 hoeing (*binage*) Nb of operations: 1	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Beginning of March	Nb of operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 200	Mineral P/K fertilizers applications			

		P, 300 K	Total number of treatment operations			
	Beginning of March	Nb of operations: 1 Total amount (in kg/ha): 100N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		*Vinasse* on intermediate crop mustard	Organic N fertilizer applications Total number of treatment operations			
Molluscicide	End of March (emergence)	Metaldehyde (1/10 year) TFI 0.1	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			Reduction of molluscicide
Herbicide	End of March	Localised on row TFI 0.5		Against mono and dicotyledonous	Mechanical weeding (no treatment between rows)	
Fungicide	Spring	1 fungicide and one more if problems, 1/5 year TFI 1.2		Against *oïdium, granulariose, cercosporiose*	Resistant cultivar	Reduction of fungicide
Insecticide		No			No treatment because of seed treatment	No insecticide
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No	Irrigation			
Harvest	Beginning of October	Operation: high fuel cost Expected yield: 95 t/ha (range 80-105)	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage		No				
Intermediate crop		no				
CROP 2: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide **Diseases**: late sowing, resistant hardy cultivars, low N fertilization, lower density **Insects**: late sowing (autumn aphids), insecticides 1/5 year **Lodging**: late sowing, low N fertilization, lower density **Slugs**: late sowing					
Drilling	Early November	Cultivar: hardy Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar	No insecticide Autumn Less fungicide

					and late sowing	
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility and allow more false seedbed		Reduction of herbicide
		Density: 250 pl /m²	Sowing density			
Mechanical weeding	Beginning of March	1 harrowing (*herse etrille*) (1/2 year) Nb of operations: 1/2	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 90N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
	Mid April	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Late sowing	
Herbicide	May	Against dicot and monocotyledonous TFI 1 Nb of operations: 1				Reduction of herbicide
Fungicide	April	Fungicide against foliar disease TFI 0.5		Reduce foliar disease	Cultivar, low N fertilization, sowing date and density	Reduction of fungicide
Insecticide	Spring	Insecticide against aphids (1/5 year) TFI 0.2		Reduce aphids		
Growth regulator		No			Late sowing, low N fertilization, low sowing density	
Other chemical product		No				
Biological control product (elicitor, pheromone…)						
Irrigation		no				
Harvest	Mid-July	Operation: classic (no additional cost) Expected yield 80q (range 70-90)	Fuel consumption at harvest			

		Straws chopped and burried	Stubble management	Avoid slugs	☺Soil organic matter	
POST-HARVEST MANAGEMENT/ pre drilling tillage	Early august (just after harvest of preceding crop)	Stubble breaking (cover crop) + rolling *(roulage)* Nb of operations: 2	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
Intermediate catch crop	Beginning of August	Mustard 12kg/ha				
		Broadcast sowing + harrowing + rolling Nb of operations: 3	Superficial tillage between crops			
	February	Mechanical breaking (if not killed by frost) Nb of operations: 1	Superficial tillage between crops		☺Low risk of nitrate leaching	Reduction of herbicide (No glyphosate)
	End of February	Ploughing (Inversion tillage)	Deep tillage, Tillage type (inversion)	Reduce weeds	☹Energy and time cost	Reduction of herbicide
CROP 3: hemp	**Weeds**: competitive crop **Diseases**: no problem of disease **Insects**: no problem					
Drilling	Beginning of May (on heated soil)	No specific cultivar	Additional seed cost of cultivar, yield reduction due to cultivar	Competitive crop limit weeds		No herbicide
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 300 pl /m²	Sowing density			
Mechanical weeding		No	Superficial tillage in crops			
Mineral Fertilization	Mid May	Nb of operations: 1 Total amount: 100N	Mineral N fertilizer applications Total number of treatment operations			
	Mid May	Nb of operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 200 P, 300 K	Mineral P/K fertilizers applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No				
Herbicide		No				
Fungicide		No				
Insecticide		No				

Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		no	Irrigation			
Harvest	Beginning of September	Operation: harvest of grains, mowing, drying, press: high fuel cost Expected yield: 800q/ha (range 600-1000)	Fuel consumption at harvest			
		Straws buried	Stubble management	Avoid slugs	☺Soil organic matter	Less molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	Beginning of September	Stubble breaking (covercrop) Nb of operations: 1	Superficial tillage between crops			
	October	Stale seedbed (vibro) Nb of operations : 1-2	Superficial tillage between crops	Decrease autumn weeds seedbank	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide
Intermediate crop		No				
CROP 4: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide **Diseases**: late sowing, resistant hardy cultivars, low N fertilization, lower density **Insects**: late sowing (autumn aphids), insecticides 1/5 year **Lodging**: late sowing, low N fertilization, lower density **Slugs**: late sowing, superficial tillage (eggs)					
Drilling	Early November	Cultivar: hardy Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar	Limit disease	☹Yield loss risk due to cultivar and late sowing	Less fungicide
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility, Avoid autumn insect and allow more false seedbed		Reduction of herbicide and no autumn insecticide
		Density: 250 pl /m²	Sowing density	Limit disease		
Mechanical weeding	Beginning of March	1 harrowing (*herse etrille*) (1/2 year) Nb of operations: 1/2	Superficial tillage in crops	Limit weeds	☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 90N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	

	Mid April	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Late sowing, superficial tillage (eggs)	
Herbicide	May	Against dicot and monocotyledonous TFI 1 Nb of operations: 1				Reduction of herbicide
Fungicide	April	Fungicide against foliar disease TFI 0.75			Cultivar, low N fertilization, sowing density and date	Reduction of fungicide
Insecticide	Spring	Insecticide against aphids (1/5 year) TFI 0.2				
Growth regulator		No			Late sowing, low N fertilization, low sowing density	
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		no				
Harvest	Mid-July	Operation: classic (no additional cost) Expected yield 75q (range 65-85)	Fuel consumption at harvest			
		Straws chopped and buried	Stubble management	Avoid slugs		No molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of July (just after harvest of preceding crop)	Stubble breaking (cover crop) + rolling *(roulage)* Nb of operations: 2	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
	End of July	Ploughing (Inversion tillage)	Deep tillage, Tillage type (inversion)	Reduce weeds	☹Energy and time cost	Reduction of herbicide
CROP 5: winter oilseed rape	**Weeds**: early sowing, competitiveness **Diseases**: early sowing, resistant cultivars **Insects pests**: favour natural enemies, margin and early cultivars (mixture) to trap pollen beetle, insecticides if necessary					

Drilling	Early august	Cultivar: resistant against phoma, earliness: cultivar mixture with 10% early cultivars Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar. 10% early cultivars to trap pollen beetles	No fungicide against phoma No insecticide against pollen beetle Reduction of herbicide, insecticide, molluscicide
		Combined tool (Seeder+superficial tool) + roll Nb of operations: 2 (count 3 in DEXiPM because of combined tool)	Superficial tillage between crops	Early sowing: more competitiveness with weeds, decrease diseases susceptibility (phoma), less susceptible to slugs and autumn insects		
		Density: 45 pl /m²	Sowing density	High density to increase competitiveness against weeds		
Mechanical weeding		No				
Mineral Fertilization	Early august	Nb of operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 100 P, 150 K	Mineral P/K fertilizers applications Total number of treatment operations			
	End of January	Nb of operations: 1 Total amount (in kg/ha): 70N	Mineral N fertilizer applications Total number of treatment operations			
	Beginning of march	Nb operations: 1 75S	Total number of treatment operations			
	Mid February	Nb operations: 1 Total amount (in kg/ha): 60N	Mineral N fertilizer applications Total number of treatment operations			
	End of March	Nb operations: 1 Total amount (in kg/ha): 80N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide	End of August (emergence)	Metaldehyde (1/5 year) TFI 0.2	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide		Early sowing less favourable to slugs	Reduction of molluscicide
Herbicide	End of August (emergence)	Systematic but reduced dose TFI 0.8			Competitiveness	
	March	Herbicide 1/3 year			Competitiveness	

		TFI 0.33	application			
Fungicide	April (flowering)	Against sclerotinia TFI 0.8	Total number of treatment operations		Resistant cultivar against phoma and early sowing	No fungicide against phoma
Insecticide	Spring	Karate zeon (weevils) TFI 2			Cultivar mixture: no treatment against pollen beetle No treatments against flea beetle (*petite altise*) and fly (*mouche*) because of early sowing	Reduction of insecticide
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No	Irrigation			
Harvest	Beginning of July	Operation: classic (no additional cost) Expected yield: 38 qx/ha (range 30-40)	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of august	Stubble breaking (cover crop) Nb of operations: 1	Superficial tillage between crops	After the emergence of volunteers to avoid rape seedbank		Reduction of herbicide
	September-October	Stale seedbed (lemken) Nb of operations : 3	Superficial tillage between crops	Destruction of weeds Destruction of seedling: less favourable to slugs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide No molluscicide
Intermediate crop		No				
CROP 6: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide **Diseases**: late sowing, resistant hardy cultivars, low N fertilization, lower density **Insects**: late sowing (autumn aphids), insecticides 1/5 year **Lodging**: late sowing, low N fertilization, lower density **Slugs**: late sowing					
Drilling	Early November	Cultivar: hardy Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar and late sowing	less fungicide

		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility and allow more false seedbed		Reduction of herbicide and no autumn insecticides, and molluscicide
		Density: 250 pl /m²	Sowing density			
Mechanical weeding	Beginning of March	1 harrowing (*herse etrille*) (1/2 year) Nb of operations: 1/2	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 90N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
	Mid April	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Late sowing	No molluscicide
Herbicide	May	Against dicot and monocotyledonous TFI 1 Nb of operations: 1				Reduction of herbicide
Fungicide	April	Fungicide against foliar disease TFI 0.75			Cultivar, low N fertilization	Reduction of fungicide
Insecticide	Spring	Insecticide against aphids (1/5 year) TFI 0.2				
Growth regulator		No			Late sowing, low N fertilization, low sowing density	No regulator
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		no				
Harvest	Mid-July	Operation: classic (no additional cost) Expected yield 75q (range 65-85)	Fuel consumption at harvest			
		Straws chopped and buried	Stubble management	Avoid slugs		No molluscicide
POST-HARVEST MANAGEMENT/	End of July (just after harvest of	Stubble breaking (cover crop) + rolling *(roulage)*	Superficial tillage between crops	Favour emergence of cereals volunteers		Reduction of herbicide

pre drilling tillage	preceding crop)	Nb of operations: 2 (count 3 in DEXiPM because of combined tool)		and of some weeds		
Intermediate catch crop	Beginning of August	Mustard 12kg/ha				
		Broadcast sowing + harrowing + rolling Nb of operations: 3	Superficial tillage between crops			
	February	Mechanical breaking (if not killed by frost) Nb of operations: 1	Superficial tillage between crops		☺Less risk of nitrate leaching	Reduction of herbicide (No glyphosate)
	End of February	Ploughing (Inversion tillage)	Deep tillage, Tillage type (inversion)	Reduce weeds	☹Energy and time cost	Reduction of herbicide

Principles: *principles of the AS/IS are proposed regarding the main pest risk identified in the current system*

Pest	Scale	Main crop protection strategies, main principles	Aim Impact on pests (weeds, diseases, insect pests)	Others impacts disadvantages & advantages
WEEDS	**Cropping system**	Diversifying sowing periods by introducing spring crops and shifting sowing dates (early/late sowing dates	Non-specialized weed flora: reduce autumn weed seedbank To allow false seedbed between harvest and drilling (late sowing or spring crops)	☹Risk to increase spring weeds seedbank ☹Energy and time cost (false seedbed) ☹Risk to increase NO3 leaching if bare soil (spring crops) ☺Positive impact on diseases (sowing dates)
		Increase the frequency of crops with high competitiveness against weeds (Triticale) and perennial crops (alfalfa). Chose cultivar with high competitiveness	To reduce weed seedbank	☹Delivery constraints for some crops
		Mechanical cultivation	To reduce TFI	☹Energy and time cost
	Crop: WOSR	Diversifying sowing periods: early sowing date	To increase competition against weeds	☺Also efficient to decrease susceptibility to phoma, slugs and autumn insects (*e.g.* weevils): less fungicide and insecticide ☹Might be lodging problems as no growth regulator ☹Efficient only if sufficient nitrate
	Crop: winter wheat	Diversifying sowing periods: late sowing date	False seedbed To reduce autumn weeds seedbank	☺Also efficient to decrease susceptibility to diseases, slugs and aphids causing BYD (no autumn insecticide against aphids, less fungicide) ☹Energy and time cost ☹Risk of lower yield ☹Risk of unsuitable sowing conditions
		Herbicides (foliar in spring) against grasses and/or against dicotyledonous if mechanical weeding is not sufficiently efficient	To limit weeds	
	Crop: spring barley	Herbicides (foliar) against grasses and/or against dicotyledonous if mechanical weeding is not efficient, particularly after sunflower	To limit weeds	
		Sown as soon as possible	Competition against spring weeds	☹Efficient only if sufficient nitrate
	Crop: sunflower	Herbicides against grasses if mechanical weeding is not efficient	To limit grasses	
INSECTS PESTS	**Landscape**	Small fields (<10 ha), settlement of hedges or other non-productive areas	To favour natural enemies	☹May impose to reorganise crop mosaic
		Flowering strips for pollinators (syrphae), refuges for ladybugs in winter	To favour natural enemies populations against aphids	
		Turnip rape (*Brassica rapa*) on WOSR margins	To attract pollen beetles	☹Loss of productive area
	Cropping system	No deep ploughing	To favour soil natural enemies	

			populations (*e.g.* carabidae)	
	Crop: WOSR	Mixture with early cultivars	To limit pollen beetles (trapped)	
		Insecticides if problems with more harmful insects (mostly weevils)	To limit weevils	
	Crop: winter wheat	No Autumn insecticides against aphids (late sowing date Spring insecticide against aphids if problems (1/10 year)	To limit aphids and BYD	
DISEASE	**Cropping system**	Diversifying crops in the rotation	To increase duration between the same crop	☹Lower frequency of cash crops
	Crops	Use of resistant cultivars against disease with various earliness, cultivar mixture		☹Resistant cultivars sometimes less productive ☹Delivery constraints with cultivar mixture
		Use of contans each year (biological control method) against sclerotinia		☹Economical cost
SLUGS	**Crops**	Export straws		☹Decrease of soil organic matter

<u>IS prototype</u>

LANDSCAPE MANAGEMENT PRACTICES

Landscape management	**Period**	**Practice**	**DEXiPM inputs**	**Observations**
Field margin		Margin of rape field sown with turnip rape, breaking at flowering	Habitat management	Breaking at flowering to kill part of the pollen beetle Yield loss for WOSR (less area)
Non-productive area		Hedges, flowering strips…	Habitat management	Increase natural enemies populations
Other landscape management that could be mentioned, not in the present system				
Surrounding fields		*Stubble management (stubble as source of inoculum for new fields, e.g. phoma stem canker), Species and cultivars choice and distribution at the landscape scale (collective management of resistance durability, GM management), etc...*	*Pest pressure includes cultivar distribution*	

CROP MANAGEMENT PRACTICES

Crop management	**Period (decade)**	**Practice and description**	**DEXiPM inputs (described in detail in the attached table)**	**Effect on pests (weeds, diseases, insect pests)**	**Observations / disadvantages**	**Pesticide reduction**
CROP SEQUENCE		**Winter oilseed rape-winter wheat-spring barley-alfalfa-alfalfa-winter wheat-(Mustard)-sunflower-triticale**	**Nb of crops, proportion of summer crops, of late-harvest crops, crop type (winter, spring, summer, perennial), crop effect on pollinators, soil cover**			

Pre-drilling tillage	Early august (just after harvest of preceding crop)	Stubble breaking (cover crop) Nb of operations: 1	Superficial tillage between crops	Favour emergence of cereals volunteers and of some weeds		Reduction of herbicide
	Early august	Stale seedbed (lemken) Nb of operations: 1	Superficial tillage between crops	Destruction of seedling: less favourable to slugs	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide No molluscicide
		Deep tillage: no	Deep tillage	Preserve soil natural enemies		
		Inversion tillage: no	Tillage type (inversion)	Preserve soil natural enemies		
CROP 1: winter oilseed rape	**Weeds**: early sowing and N application at sowing localised on row to increase competitiveness on row, mechanical weeding between rows **Diseases**: early sowing, resistant cultivars, biological control (contans) **Insects pests**: favour natural enemies, margin and early cultivars (mixture) to trap pollen beetle, insecticides if necessary					
Drilling	Early august	Cultivar: resistant against phoma, earliness: cultivar mixture with 10% early cultivars Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar	10% early cultivars to trap pollen beetles (in addition to turnip rape)	☹Yield loss risk due to cultivar	No fungicide against phoma No insecticide against pollen beetle Reduction of herbicide, insecticide, molluscicide
		Combined tool (Seeder+superficial tool) + roll Nb of operations: 2 (count 3 in DEXiPM because of combined tool)	Superficial tillage between crops	Early sowing: favour competitiveness with weeds, limit diseases susceptibility (phoma), limit susceptibility to slugs and to some autumn insects		
		Density: 45 pl /m² (row spacing 45cm)	Sowing density	Wide row spacing for mechanical weeding		
Mechanical weeding	Autumn	2 harrowing (*herse etrille*) + 2 hoeing (*binage*) Nb of operations: 4	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
	Spring	1 hoeing (*binage*) Nb of operations: 1	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Early august	Nb of operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 100 P, 150 K, 100 N	Mineral P/K fertilizers applications Total number of treatment operations			
	Early august	Nb of operations: 1 Total amount (in kg/ha): 100 N	Mineral N fertilizer applications Total number of treatment operations	N application localised on the row to enhance		

				competitiveness of WOSR against weeds		
	End of January	Nb of operations: 1 Total amount (in kg/ha): 70N	Mineral N fertilizer applications Total number of treatment operations			
	Beginning of march	Nb operations: 1 75S	Total number of treatment operations			
	Mid march	Nb operations: 1 Total amount (in kg/ha): 70N	Mineral N fertilizer applications Total number of treatment operations			
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide	End of August (emergence)	Metaldehyde 0.3kg (field margin) TFI 0.3	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Early sowing less favourable to slugs	Reduction of molluscicide
Herbicide		No			Competitiveness on row and mechanical weeding between rows	No herbicide
Fungicide		No			Resistant cultivar and early sowing (phoma), contans against sclerotinia	
Insecticide	Spring	Karate zeon (weevils) TFI 1,5 (between 1 and 2 depending on the pressure)		Threshold for treatment if field margin (turnip rape) or cultivar mixture (10% early cultivar) not efficient enough		Reduction of insecticide
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)	Sowing	Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide
Irrigation		No	Irrigation			

Harvest	Mid June	Operation: classic (no additional cost) Expected yield: 25 qx/ha	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of august	Stubble breaking (cover crop) Nb of operations: 1	Superficial tillage between crops	After the emergence of volunteers to avoid rape seedbank		Reduction of herbicide
	September-October	Stale seedbed (lemken) Nb of operations : 3	Superficial tillage between crops	Destruction of weeds Destruction of seedling: less favourable to slugs and destruction of slug egg	☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide No molluscicide
Intermediate crop		no				
CROP 2: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide if necessary **Diseases**: late sowing, cultivar mixture with resistant cultivars, low N fertilization, low density **Insects**: late sowing (autumn aphids), bearded cultivars, natural enemies favoured, insecticides if necessary **Lodging**: late sowing, low N fertilization, low density **Slugs**: late sowing, superficial tillage					
Drilling	Early November	Cultivar: cultivar mixture (bearded, resistant against aerial disease) Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar and late sowing	No fungicide
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility, allow more false seedbed, less autumn insects and slugs		Reduction of herbicide, insecticide No fungicide and molluscicide
		Density: 200 pl /m²	Sowing density			
Mechanical weeding	Autumn	2 harrowing (*herse etrille*) Nb of operations: 2	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator and fungicide
	Mid April	Nb of operations: 1 Total amount: 50N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No growth regulator and fungicide
Organic Fertilization		No	Organic N fertilizer applications Total number of treatment operations			
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI		Late sowing	
Herbicide	Beginning of March	Archipel (sulfonylurée) TFI 0.5 (1 out of 2 years)		If mechanical weeding is not		Reduction of herbicide

			Pesticide mobility	efficient		
Fungicide		No	Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations		Cultivar, late sowing date, low sowing density, low N fertilization	
Insecticide	May	Mavrick flo (aphids) TFI 0.1 (1 out of 10 years)		Extraordinary: only if 100% of ears have more than 5 aphids	Late sowing date	Reduction of insecticide No autumn insecticide against aphids/BYD
Growth regulator		No			Late sowing, low N fertilization, low sowing density	
Other chemical product		No				
Biological control product (elicitor, pheromone…)	Sowing	Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide on WOSR and sunflower
Irrigation		no	Irrigation			
Harvest	Mid july	Operation: classic (no additional cost) Expected yield: 55q/ha	Fuel consumption at harvest			
		Straws exported	Stubble management	Avoid slugs	☹Soil organic matter	No molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	July (at harvest of wheat)	Stubble breaking (covercrop) Nb of operations: 1	Superficial tillage between crops			
	From August to November	Stale seedbed (lemken) Nb of operations : 4	Superficial tillage between crops	Decrease autumn weeds seedbank Destruction of slug eggs	☹Energy and time cost ☹Risk of nitrate leaching	Reduction of herbicide, no molluscicide on next crop
Intermediate crop		No			☹Risk of nitrate leaching	
CROP 3: spring barley	**Weeds**: early sowing to differentiate weed flora with sunflower, mechanical weeding, herbicide if necessary **Diseases**: resistant cultivar, low N fertilization **Lodging**: low N fertilization **Slugs**: superficial tillage					
Drilling	February	Cultivar: cultivar resistant against aerial diseases Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar Collecting firms	No fungicide

					often impose the cultivar for technological quality	
		Combined tool (seeder+superficial tool) Nb of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Sowing as soon as possible: increase spring weed competitiveness Differentiate weed flora with sunflower	☺Sowing as soon as possible: limit risk of nitrate leaching	
		Density: 250 pl /m²	Sowing density			
Mechanical weeding	Beginning of March	1 harrowing (*herse etrille*) Nb of operations: 1	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
	April	1 harrowing (*herse etrille*) Nb of operations: 1	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	February	Nb of operations: 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	No fungicide, no regulator
Organic Fertilization		No				
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity Soil cover at pesticide application Total number of treatment operations			
Herbicide	end of march	Embutone (against dicotyledonous) TFI 0.5 (1 out of 2 years)		If mechanical weeding is not efficient enough		Reduction of herbicide
Fungicide		No			Cultivar, low N fertilization	
Insecticide		No				
Growth regulator		No			Low N fertilization	
Other chemical product		No				
Biological control product (elicitor, pheromone…)	Sowing	Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide on WOSR and sunflower
Irrigation		no				
Harvest	End of July	Operation: classic (no additional cost) Expected yield 40 q/ha	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of July	Stubble breaking (covercrop) Nb of operations: 1	Superficial tillage between crops			
	August	Stale seedbed (lemken)	Superficial tillage between crops		☹Energy and	Reduction of herbicide

		Nb of operations : 2			time cost ☹Risk of Nitrate leaching	
Intermediate crop		no				
CROP 4: alfalfa	**Weeds**: maximize soil cover (early sowing, mowing not too frequent)					
Drilling	End of August	Combined tool (seeder+superficial tool) Nb of operation: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
Mechanical weeding		No				
Mineral Fertilization	Beginning September	Nb operations: 1 Total amount (in P_2O_5/K_2O kg/ha): 300K, 100P	Mineral P/K fertilizer applications Total number of treatment operations			
Organic Fertilization		No				
Molluscicide		No				
Herbicide		No		Several mowing		
Fungicide		No				
Insecticide		No				
Growth regulator		No				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		No				
Irrigation		No				
Harvest	Beginning June, 15 July, end of August	Operations: 3 tools: mowing + windrowing (*andainage)* + press : high fuel cost Expected yield: 9t/year (4+3+2)	Fuel consumption at harvest	Early mowing to avoid alfalfa seedbank constitution	☹Energy and time cost	
CROP 5: alfalfa						
Mineral Fertilization	Autumn	Nb operations: 1 Total amount (in K_2O kg/ha): 200K	Mineral K fertilizer applications Total number of treatment operations			
Harvest	Beginning June, 15 July, end of August	Operations: 3 tools: mowing + windrowing (*andainage)* + press: high fuel cost Expected yield: 9t/year (4+3+2)	Fuel consumption at harvest		☹Energy and time cost	
POST-HARVEST MANAGEMENT/ pre drilling tillage	September	Mouldboard ploughing	Deep tillage, tillage type (inversion)			
	September	1 harrowing (*herse rotative*)	Superficial tillage between crops			Reduction of herbicide

		Nb of operations: 1				
	End October	Stale seedbed (lemken) Nb of operations: 1	Superficial tillage between crops		☹Energy and time cost ☹Risk of Nitrate leaching	Reduction of herbicide
Intermediate crop		no				
CROP 6: winter wheat	**Weeds**: late sowing (false seedbed), mechanical weeding, spring herbicide if necessary, low row spacing: competitiveness (effect of distribution of plants rather than density) **Diseases**: late sowing, cultivar mixture with resistant cultivars, low N fertilization, low density **Insects**: late sowing (autumn aphids), bearded cultivars, natural enemies favoured, insecticides if necessary **Lodging**: late sowing **Slugs**: late sowing					
Drilling	Early November	Cultivar: cultivar mixture (bearded, resistant against aerial disease) Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar and late sowing	No fungicide
		Combined tool (seeder+superficial tool) Number of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops	Late sowing: disease susceptibility and allow more false seedbed		Reduction of herbicide, no autumn insecticide
		Density: 250 pl /m^2 (low row spacing)	Sowing density	Low row spacing: competitiveness		Reduction of herbicide
Mechanical weeding	Autumn	2 harrowing (*herse etrille*) Number of operations: 2	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Mid March	Nb of operations: 1 Total amount: 60N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk. Less than in the previous wheat because of alfalfa effect	
	Mid April	Nb of operations: 1 Total amount: 50N	Mineral N fertilizer applications Total number of treatment operations	Low N application: reduce disease risk	☺Low N application: reduce lodge risk	
Organic Fertilization		No				
Molluscicide		No	TFI of herbicide/fungicides/insecticides Total pesticide TFI Pesticide mobility Pesticide eco-toxicity		Late sowing	
Herbicide	May	Archipel (sulfonylurée) TFI 0.25 (1/4 year) Nb of operations: 1		If mechanical weeding is not efficient.	Less frequent in comparison with the previous wheat because of	Reduction of herbicide

			Soil cover at pesticide application Total number of treatment operations		alfalfa effect and low row spacing (competitiveness) and mechanical weeding	
Fungicide		No			Cultivar, late sowing date, low sowing density, low N fertilization	No fungicide
Insecticide	May	Mavrick flo (aphids) TFI 0.1 (1 out of 10 years)		Extraordinary: only if 100% of ears have more than 5 aphids	Late sowing date	Reduction of insecticide No autumn insecticides against aphids/BYD
Growth regulator		No			Late sowing, low N fertilization, low sowing density	No growth regulator
Other chemical product		No				
Biological control product (elicitor, pheromone…)		Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide on WOSR and sunflower
Irrigation		no				
Harvest	Mid July	Operation: classic (no additional cost) Expected yield 55q	Fuel consumption at harvest		☺Higher expected yield because of alfalfa effect (soil structure)	
		Straws exported	Stubble management	Avoid slugs	☹Soil organic content	No molluscicide
POST-HARVEST MANAGEMENT/ pre drilling tillage	Mid July	Stubble breaking	Superficial tillage between crops			
	End of July	False seedbed (lemken) Nb of operation: 1	Superficial tillage between crops		☹Energy and time cost	
Intermediate catch crop	Beginning of August	Mustard 12kg/ha			☺Lower risk of nitrate leaching	
		Broadcast sowing + harrowing + rolling Number of operations: 3	Superficial tillage between crops			

	November	Mechanical breaking	Superficial tillage between crops			Reduction of herbicide (No glyphosate)
CROP 7: sunflower	**Weeds**: mechanical weeding **Diseases**: resistant cultivar, biological control against sclerotinia (contans) **Insects**: favour natural enemies against aphids					
Drilling	End of April	Cultivar: early cultivar, multi-resistant Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar			No fungicide
		Combined tool (seeder+superficial tool) Number of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 7 pl /m²	Sowing density			
Mechanical weeding	May-June	2 hoeing (*binage*) Number of operations: 2	Superficial tillage in crops		☹Energy and time cost	No herbicide
Mineral Fertilization	End of April	Nb of operations : 1 Total amount: 100P, 150K	Mineral P/K fertilizer applications Total number of treatment operations		☺No N because of restitution by intermediate catch crop	
Organic Fertilization		No				
Molluscicide		No				
Herbicide		No				
Fungicide		No			Resistant cultivar	
Insecticide		No				
Growth regulator		No on sunflower				
Other chemical product		No				
Biological control product (elicitor, pheromone…)		Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide
Irrigation		No				
Harvest	End September	Operation: classic (no additional cost) Expected yield 25q/ha	Fuel consumption at harvest			
POST-HARVEST MANAGEMENT/ pre drilling tillage	End of September	Stubble breaking (covercrop) Nb of operations: 1	Superficial tillage between crops	Limit weeds, destruction of seedlings (slugs)		Reduction of herbicide No molluscicide
	Beginning October	False seedbed (lemken) Nb of operations: 1	Superficial tillage between crops	Limit weeds, destruction of seedlings (slugs)	☹Energy and time cost	Reduction of herbicide No molluscicide
CROP 8: triticale	**Weeds**: false seedbed, late sowing, high sowing density, mechanical weeding **Diseases**: resistant cultivar, late sowing, low N fertilization					

	Lodging: low N fertilization **Slugs**: late sowing					
Drilling	End of October	Cultivar: resistant Non-treated seeds	Additional seed cost of cultivar, yield reduction due to cultivar		☹Yield loss risk due to cultivar and late sowing	No fungicide
		Combined tool (seeder+superficial tool) Number of operations: 1 (count 2 in DEXiPM because of combined tool)	Superficial tillage between crops			
		Density: 300 pl /m² (high)	Sowing density	High density: competitiveness against weeds		Reduction of herbicide
Mechanical weeding	Autumn	2 harrowing (*herse étrille*) Number of operations: 2	Superficial tillage in crops		☹Energy and time cost	Reduction of herbicide
Mineral Fertilization	Beginning march	Nb of operations : 1 Total amount: 70N	Mineral N fertilizer applications Total number of treatment operations		Higher N fertilization than wheat because of sunflower as preceding crop (high N consumption)	
	Beginning April	Nb of operations : 1 Total amount: 80N	Mineral N fertilizer applications Total number of treatment operations		Higher N fertilization than wheat because of sunflower as preceding crop (high N consumption)	
Organic Fertilization		No				
Molluscicide		No			Late sowing	
Herbicide		No			Late sowing, mechanical weeding	
Fungicide		No			Cultivar, late sowing date, low N fertilization	
Insecticide		No				
Growth regulator		No			Late sowing, low N fertilization	
Other chemical product		No				

Biological control product (elicitor, pheromone…)		Contans: 1kg	Total number of treatment operations	Biological control against sclerotinia on WOSR and sunflower (each year)	☹Economical cost	No fungicide on WOSR and sunflower
Irrigation		No				
Harvest	Mid July	Operation: classic (no additional cost) Expected yield 52q	Fuel consumption at harvest			
		Straws exported		Avoid slugs	Soil organic matter	No molluscicide

Germany

Appendix B: List of major pests in winter wheat, winter barley and winter oilseed rape for each country

Denmark

A1. Winter wheat – **weeds** (listing according to economic importance,)

Dicots	Monocots	Perennials
Tripleurospermum inodorum	*Apera spica-venti*	*Elymus repens*
Papaver rhoeas	*Lolium perenne*	*Cirsium arvensis*
Galium aparine	*Alopecurus myosuroides*	*Artemisia vulgaris*
Stellaria media	*Poa trivialis*	
Viola arvensis	*Poa annua*	
Capsella bursa-pastoris		
Fallopia convolvulus		
Polygonum aviculare		

A2. Winter wheat – **diseases** (information available in wheat case study also for the German situation)

Air born	Soil born	Seed born	Debris spread
Septoria leaf blotch (*Mycosphaerella graminicola*)	Take all (*Gaeumannomyces graminis var. tritici*)	Stinking smut (*Tilletia tritici*)	Septoria leaf blotch (*Mycosphaerella graminicola*)
Leaf rust (*Puccinia triticina*)	Stinking smut (*Tilletia tritici*)	Fusarium head blight (*Fusarium spp.*)	Tan spot (*Pyrenophora tritici-repentis*)
Yellow (stripe) rust (*Puccinia striiformis*)	Ergot (*Claviceps purpurea*)	Ergot (*Claviceps purpurea*)	Eyespot (Oculimacula spp.)
Powdery mildew (*Blumeria graminis f. sp. tritici*)		Leaf and Glume Blotch (*Phaeosphaeria nodorum*)	Fusarium head blight (*Fusarium spp.*)

A3. Winter wheat – **pests**

Mobile	Less mobile	Soil born
Aphids / virus vector *(Sitobion avenae, Metopolophium dirhodum, Rhopalosiphum padi)*	Orange wheat blossom midge (*Sitodiplosis mosellana*)	Slugs (*Deroceras agreste & D. reticulatum)*

B1. Winter barley – **weeds**

Dicots	Monocots	Perennials
Tripleurospermum inodorum	*Apera spica-venti*	*Elymus repens*

Papaver rhoeas *Galium aparine* *Stellaria media* *Viola arvensis* *Capsella bursa-pastoris* *Fallopia convolvulus* *Polygonum aviculare* *Persicaria maculosa*	*Lolium perenne* *Alopecurus myosuroides* *Poa trivialis* *Poa annua*	*Cirsium arvensis* *Artemisia vulgaris*

B2. Winter barley – **diseases** (most of the problems are also relevant for spring barley)

Air born	**Soil born**	**Seed born**	**Debris spread**
Leaf rust (*Puccinia hordei*) Mildew (*Blumeria graminis*) Net blotch (*Pyrenophora teres*) Leaf scald (*Rhynchosporium secalis*)		Smut (*Ustilago nuda f.sp. hordei*) Leaf stripe (*Drechslera graminea*) Net blotch (*Pyrenophora teres*) Fusarium head blight (*Fusarium spp.*)	Net blotch (*Pyrenophora teres*)

B3. Winter barley – **pests** (also relevant for spring barley apart from slugs)

Mobile	**Less mobile**	**Soil born**
Aphids / virus vector (*Sitobion avenae, Rhopalosiphum dirhodum, Metopolophium padi*)		Slugs (*Deroceras agreste & D. reticulatum)*

C1. Winter oil seed rape – **weeds**

Dicots	**Monocots**	**Perennials**
Sinapis arvensis *Raphanus raphanistrum* *Capsella bursa-pastoris* *Tripleurospermum inodorum* *Papaver rhoeas* *Galium aparine*	*Lolium perenne* *Alopecurus myosuroides* Volunteers (barley/wheat) *Apera spica-venti* *Poa annua*	*Elymus repens* *Cirsium arvensis*

C2. Winter oil seed rape – **diseases** (include fungicide as a growth regulator)

Air born	**Soil born**	**Seed born**	**Debris spread**
Alternaria (*Altenaria spp*)	Sclerotinia stem rot (*sclerotinia sclerotium*)	*Phoma (Phoma lingam)*	*Phoma (Phoma lingam)*

Phoma (Phoma lingam) *Grey rot (Botrytis cinerea*)	*Clubroot* (*Plasmodiophora brassicae)*	Alternaria (*Altenaria spp*)

C3. W. oil seed rape – **pests**

Mobile	Less mobile	Soil born
Pollen beetle (*Meligethes aeneus*) Cabbage stem flea beetle (*Psylliodes chrysocepthala)* Cabbage seed weevil (*Ceutorhynchus assimilis*)	Brassica pod midge (*Dasineura brassicae*)	Slugs (*Deroceras agreste & D. reticulatum)*

France

A1. Winter wheat – **weeds** (listing according to economic importance)

Dicots	**Monocots**	**Perennials**
Galium aparine	*Alopecurus myosuroides*	*Cirsium arvensis*
Stellaria media	*Apera spica-venti*	*Elymus repens (Elytrigia repens)*
Viola arvensis	*Lolium perenne*	
Capsella bursa-pastoris	*Bromus sterilis*	
Sinapis arvensis	*Poa annua*	
Veronica hederifolia		
Tripleurospermum inodorum		

A2. Winter wheat – diseases (information available in wheat case study also for the German situation)

Air born	**Soil born**	**Seed born**	**Debris spread**
Septoria tritici (all 1)	Take all	Tilletia	*Septoria tritici* (all 1)
Brown rust (FR 2)	Tilletia	*Fusarium*	Tanspot
Yellow rust	Ergot	Ergot	Eyespot
Powdery mildew			Fusarium (FR 3)

‘FR 2’ means that brown rust would be ranked second in France and ‘FR 3’ third in France

A3. Winter wheat – pests

Mobile	**Less mobile**	**Soil born**
Aphids / virus vector *Sitobion avenae, Rhopalosiphum dirhodum, Rhopalosiphum padi*	Orange wheat blossom midge	Slugs

Cikade (virus vector)

B1. Winter barley – weeds

Dicots	Monocots	Perennials
Galium aparine	*Alopecurus myosuroides*	*Cirsium arvensis*
Stellaria media	*Apera spica-venti*	*Elymus repens (Elytrigia repens)*
Viola arvensis	*Lolium perenne*	
Capsella bursa-pastoris	*Bromus sterilis*	
Sinapis arvensis	*Poa annua*	
Veronica hederifolia		
Tripleurospermum inodorum		

B2. Winter barley – diseases (most of the problems are also relevant for spring barley)

Air born	Soil born	Seed born	Debris spread
Brown rust	Take all	Ustilago	Netblotch
Mildew		Leaf stribe	*Rhynchosporium*
Netblotch		Netblotch	*Ramularia*
Rhynchosporium		*Fusarium*	
Ramularia		*Ramularia*	
		Rhynchosporium	

B3. Winter barley – pests (also relevant for spring barley apart from slugs)

Mobile	Less mobile	Soil born
Aphids / virus vector *Sitobion avenae,* *Rhopalosiphum dirhodum,* *Rhopalosiphum padi*		Slugs

C1. Winter oil seed rape – weeds

Dicots	Monocots	Perennials
Sinapis arvensis	*Lolium perenne*	*Elymus repens*
Rhaphanus raphanistrum	*Alopecurus myosuroides*	*Cirsium arvensis*
Capsella bursa-partoris	Volunteers (barley/wheat)	
Tripleurospermum inodorum	*Apera spica-venti*	
Geranium spp.		
Calepina		
Galium aparine		
Orobanche ramosa		

C2. Winter oil seed rape – diseases (include fungicide as a growth regulator)

Air born	**Soil born**	**Seed born**	**Debris spread**
Altenaria	*Sclerotinia*	*Phoma*	*Phoma*
Phoma	*Clubroot*	*Altenaria*	
Botrytis	*Verticillium*		
Cylindrosporium			
Erysiphe crucuferarium			

C3. W. oil seed rape – pests

Mobile	Less mobile	Soil born
Pollen beetle	Brassica pod midge	Slugs
Rape stem weevil		
Cabbage stem flea beetle		
Cabbage seed weevil		
Myzus persicae (virus vector)		
Pigeon		

The UK

A1. Winter wheat – **weeds** (listing according to economic importance)

Dicots	**Monocots**	**Perennials**
Galium aparine	*Apera spica-venti*	*Elymus repens*
Tripleurospermum inodorum	*Alopecurus myosuroides*	
Papaver rhoeas	*Lolium sp.*	*Cirsium arvensis*
	Anisantha sterilis	
Stellaria media	*Poa trivialis*	
Veronica persica		
Viola arvensis	*Poa annua*	
Capsella bursa-pastoris		

A2. Winter wheat – diseases (information available in wheat case study also for the German situation)

Air born	**Soil born**	**Seed born**	**Debris spread**
Septoria tritici (all 1)	Take all	Tilletia	*Septoria tritici* (all 1)

Brown rust (FR 2) Yellow rust Powdery mildew	Tilletia Ergot	*Fusarium* Ergot	Tanspot Eyespot Fusarium

A3. Winter wheat – pests

Mobile	Less mobile	Soil born
Aphids important chiefly as virus vectors in autumn: *Sitobion avenae* *Rhopalosiphum padi* Other aphids: *Metopolophium dirhodum*	Orange wheat blossom midge Wheat bulb fly	Slugs

B1. Winter barley – weeds

Dicots	Monocots	Perennials
Galium aparine	*Apera spica-venti*	*Elymus repens*
Tripleurospermum inodorum	*Alopecurus myosuroides*	
Papaver rhoeas	*Lolium sp.*	*Cirsium arvensis*
	Anisantha sterilis	
Stellaria media	*Poa trivialis*	
Veronica persica	*Poa annua*	
Viola arvensis		
Capsella bursa-pastoris		

B2. Winter barley – diseases (most of the problems are also relevant for spring barley)

Air born	Soil born	Seed born	Debris spread
Brown rust Mildew Netblotch *Rhynchosporium* *Ramularia*	Take all	Ustilago Leaf stribe Netblotch *Fusarium* *Ramularia* *Rhynchosporium*	Netblotch *Rhynchosporium* *Ramularia*

B3. Winter barley – pests (also relevant for spring barley apart from slugs)

Mobile	Less mobile	Soil born
Aphids important chiefly as virus vectors in autumn: *Sitobion avenae Rhopalosiphum padi*	Wheat bulb fly	Slugs

Other aphids:
Metopolophium dirhodum

C1. Winter oil seed rape – weeds

Dicots	Monocots	Perennials
Sinapis arvensis	*Lolium sp.*	*Elymus repens*
Rhaphanus raphanistrum	*Alopecurus myosuroides*	*Cirsium arvensis*
Galium aparine	Volunteers (barley/wheat)	
Capsella bursa-partoris		
Tripleurospermum inodorum	*Apera spica-venti*	
Papaver rhoeas		
Geranium spp.		
Sonchus sp(?).		
Calepina		
Orobanche ramosa		

C2. Winter oil seed rape – diseases (include fungicide as a growth regulator)

Air born	Soil born	Seed born	Debris spread
Altenaria	*Sclerotinia*	*Phoma/canker*	*Phoma/canker*
Phoma/canker	*Clubroot*	*Altenaria*	
Botrytis	*Verticillium*		
Cylindrosporium/ light leaf spot			
Erysiphe crucuferarium			

C3. W. oil seed rape – pests

Mobile	Less mobile	Soil born
Pollen beetle	Brassica pod midge	Slugs
Rape stem weevil		
Cabbage seed weevil		
Cabbage stem flea beetle		
Cabbage stem weevil		
Myzus persicae (virus vector)		
Pigeon		

Germany

Appendix C: The impact of agronomic practices on weeds, diseases and invertebrate pests.

Weeds – France, results and experiences

Weeds in wheat and rape		
Factor	**Description**	**Source**
Cultivars	Wheat: competitive cultivars : high tillering ability, long stems, large planophile leaves. Rape: high early vigor (i.e. high ealy relative growth rate (RGR) of leaf area) : hybrids	
Crop rotation	Diversified crop rotation (i.e. diversified sowing dates at the CS level) reduces weed problems, especially those weeds with marked emergence seasonality and low seed persistence (typically : Alopecurus myosuroides). Therefore, crop rotation should be diversified with (i) one early-spring sown crop (spring barley, spring pea, spring faba bean, …) AND (ii) one late-spring sown crop (sunflower, maize…).	Munier-Jolain, pers. Com.
Sowing date	Wheat and barley : Late sowing reduces infestations of autumn emerging species with marked emergence seasonality (Alopecurus myosuroides, Bromus sp., Lolium perenne). The effect is increased when associated with repeated shallow cultivations before sowing (as shallow as possible : false seed bed). The effect is less important with species with prolonged emergence during winter and early spring (Galium aparine). Rape : late sowing reduces the emergence of species able to emerge during summer time (Geranium species) if associated with repeated shallow cultivations before sowing (as shallow as possible : false seed bed). Early sowing increases the competitive ability against autumn-winter-spring emerging species (Alopecurus myosuroides, Galium aparine, Cirsium arvense), at least when N availability in soils is high in autumn/spring.	Rasmussen I. (2004)
Tillage	Ploughing Ploughing is efficient to manage weeds with low seed persistence (Bromus sp., Alopecurus myosuroides, Apera spica-venti, Lolium multiflorum, Galium aparine). But the frequency of ploughing might depends on the crop rotation (one and only one ploughing between 2 crops infested by the same species, to avoid	 Colbach *et al*.

	replacing buried seeds back up into the top soil layers). At least one ploughing once in the rotation would be preferable to manage grass weeds. Less efficient against weeds with long living seeds, but ploughing still have a ‘diluting’ effect. Shallow cultivations False seed bed before each sowing when time is available. As shallow as possible to avoid bringing buried seeds back to the top layers before sowing the crop. Repeated cultivation are necessary (i) to maximize the number of germinations (ii) to avoid excessive seedling growth that would reduce their mortality at the subsequent shallow cultivation. Concentrate cultivations at the seasons when species present are able to germinate. Use a shallow cultivating tool that is efficient at killing seedling (shallow Goose-foot shaped blades) Early stubble cultivation might stop seed production of weeds, but might also reduce seed predation (???)	
Mechanical weeding	Wheat : pre-emergence (autumn) and post-emergence weed-harrow or rotary hoe Barley : pre-emergence (autumn) and post-emergence (autumn, when possible) weed-harrow or rotary hoe (barley is sown earlier than wheat) Rape : post emergence weed-harrow or rotary hoe, then inter-row hoeings	ENDURE
Direct drilling in mulch	Direct drilling with a specific equipment without any soil tillage reduces weed seed germination. A mulching with residues of a cover crop might modify soil temperature and also reduce weed emergence. But the technique is not compatible with the false seed bed technique. And the destruction of the cover crop might require an herbicide (which is a problem if the objective is to reduce the reliance on herbicides), unless the chosen cover crop is sensitive to frost.	Debaeke *et al.*
Nitrogen amounts	High nitrogen availability decreases weed growth in rape, increases weed growth in wheat (ranking nitrophilly : Rape > weeds > wheat)	Valentin-Morison
Nitrogen strategy		
Crop density Row spacing	Increasing crop density and decreasing row spacing reduce weed growth (in wheat, antagonistic with disease management, but might be possible thanks to late sowings and resistant genotypes)	Olsen *et al.*, 2005 Munier-Jolain, 2004

Weeds – Denmark, results and experiences

Weeds in winter wheat and barley		
Factor	**Description**	**Source**
Variety	Varieties have different competitive abilities. Weed suppressive indexes have been formulated for spring barley and winter wheat. Differences in competitive ability may reach 60% between the most competitive variety and the least. Especially culm length is an important factor for variety competitiveness	Hansen *et al*. (2008), Christensen (1995)
Crop density	Crop densities below 200 plants m^{-2} will reduce crop competitiveness. Small differences in the area of 250-400 plants m^{-2}. Poor interaction with row spacing	Melander *et al*. (2003)
Crop establishment pattern	Increasing row spacing reduces crop competiveness against weeds, especially for spacing > 20 cm. Spatial uniformity of crop plant establishment provides more competition than row drilling. And increased seed rates improves crop competitiveness in a grid-like pattern	Melander *et al*. (2003), Olsen *et al*. (2005)
Sowing date	Delaying sowing of winter wheat and winter rye by more than 14 days will reduce weed numbers and the competitiveness of established weeds. The effect in winter barley is more vague due to its earlier sowing	Melander (1995)
Effects of nutrients	Fertiliser placement in spring improves crop yield and the more vigorous crop growth might improve crop competitiveness although not convincingly proved. Increasing nitrogen input increases crop competitiveness while low N levels can promote the proliferation of weeds.	Jørnsgaard *et al*. (1996), Melander *et al*. (2001), Melander *et al*. (2003)
Tillage tactics	Ploughing generally leads to fewer weed problems that non-inversion tillage especially if wintering crops are predominant in the rotation. Stale seed bed strategies can reduce the weed numbers emerging in the crop and probably delay their growth relative to the crop. However the effects are very dependent on soil moisture and very dry weather may lead to opposite results. Most weed seeds are preserved when incorporated deeper than 1-2 cm in the soil during the stubble period. *Bromus* species appear to be the only species deviating from that rule.	Melander & Rasmussen (2001), Melander *et al*. (2008)
Rotational effects	Diverse crop rotations are probably among the most efficient and reliable	Blackshaw *et al*. (2007),

	preventive measures that can be taken against unwanted weed growth. However, rotations need to include a broad mixture of autumn versus spring sown crops, monocot crops versus dicot and perennial crops. Especially annual grass weeds respond strongly to changes in crop rotation.	Melander *et al*. (2008)
Crop species	Introducing winter rye in the rotation will improve crop competitiveness	Blackshaw *et al*. (2007)
Harvest time	Early harvest of wheat or barley as whole crops for silage strongly prevents weed seed production and shedding	Blackshaw *et al*. (2007)
Cover crops	Cover crops serving as living mulches in fallow periods that are knocked down prior to crop planting to continue as a dead mulch in the crop have little value in winter crops based cropping systems unless spring sown crops are introduced in the rotation	Teasdale *et al*. (2007)
Volunteers	Winter wheat volunteers may play a significant role in a subsequent winter barley crop. Stubble cultivation can stimulate germination of crop seeds.	
Margins management	Undesired weed seed spread may occur from cultivated field boundaries creating room for the growth of annual weed species. However, margins can act as barriers for the spread of especially perennial weeds, if the boundaries are cultivated enough frequently to prevent weed seed production and vegetative spread of perennials.	Marshall (2009)
Landscape	No specific impact identified	Marshall (2009)
Soil type	Sandy soil are known to host larger weed populations than clayey soils	
Climate?	Rainy weather promotes weed growth in general and couch grass in particular. Increasing temperatures due to global warming can reduce the effectiveness of herbicides specifically making reduced doses inadequate	

Weeds in winter oilseed rape		
Factor	**Description**	**Source**
Variety	No information	
Crop density	Competitiveness is generally high and there is great plasticity within a large range	

	of plant numbers per m^{-2}	
Crop establishment pattern	Generally high plasticity, row spacing of 50 cm may yield as much as 12 cm row spacing.	
Sowing date	No benefits of delaying sowing date. Delayed sowing may results in poor crop establishment and development	
Effects of nutrients	No specific information available but early and vigorous crop growth is important for the competition against *Sinapis arvensis*	
Tillage tactics	Ploughing generally leads to fewer weed problems that non-inversion tillage especially if wintering crops are predominant in the rotation. Stale seed bed strategies have limited effect because dry conditions often prevail before sowing the oil seed rape. Inter-row hoeing in oil seed rape grown at 50 cm row spacing can be very effective, usually requiring 1-2 treatments in the autumn and 1 in the spring	
Rotational effects	Diverse crop rotations are probably among the most efficient and reliable preventive measures that can be taken against unwanted weed growth. However, rotations need to include a broad mixture of autumn versus spring sown crops, monocot crops versus dicot and perennial crops. Especially annual grass weeds respond strongly to changes in crop rotation.	Blackshaw *et al*. (2007), Melander *et al*. (2008)
Crop species	Introducing winter rye in the rotation will improve crop competitiveness	Blackshaw *et al*. (2007)
Harvest time	Not relevant	Blackshaw *et al*. (2007)
Cover crops	The duration between harvest of the preceding crop and winter oil seed rape is too short for attaining any benefits from cover cropping in the fallow period. Establishing oil seed rape successfully in a dead mulch is not possible.	Teasdale *et al*. (2007)
Volunteers	Winter barley volunteers may play a significant role. Stubble cultivation can stimulate germination of crop seeds but dry weather and the short duration from harvest of winter barley to winter oil seed rape reduces can reduce the effect	
Margins management	Undesired weed seed spread may occur from cultivated field boundaries creating room for the growth of annual weed species. However, margins can act as barriers for the spread of especially perennial weeds, if the boundaries are cultivated enough frequently to prevent weed seed production and vegetative spread of perennials.	Marshall (2009)

Landscape	No specific impact identified	Marshall (2009)
Soil type	Sandy soil are known to host larger weed populations than clayey soils	
Climate?	Rainy weather promotes weed growth in general and couch grass in particular. Increasing temperatures due to global warming can reduce the effectiveness of herbicides specifically making reduced doses inadequate	

References

Blackshaw RE, Anderson RL & Lemerle D (2007). *Cultural Weed Management*. Non-Chemical Weed Management: Principles, Concepts and Technology, (Editors: M.K. Upadhyaya & R. E. Blackshaw). CAB International (www.cabi.org), Wallingford (UK), 35-47.

Christensen S (1995) Weed suppression ability of spring barley varieties. Weed Research 35, 241–247.

Hansen PK, Kristensen K. & Willas J. (2008). A weed suppressive index for spring barley (*Hordeum vulgare*) varieties. Weed Research 48, 225-236

Jørnsgard B, Rasmussen K, Hill J, *et al*. (1996). Influence of nitrogen on competition between cereals and their natural weed populations. Weed Research 36(6), 461-470

Marshall J (2009). The impact of landscape structure and sown grass margin strips on weed assemblages in arable crops and their boundaries. Weed Research 49, 107-115

Melander B. (1995). Impact of drilling date on *Apera spica-venti* L. and *Alopecurus myosuroides* Huds. in winter cereals. *Weed Research, 35, 157-166.*

Melander B., Rasmussen K., Rasmussen I.A. & Jørgensen M.H. (2001). Radrensning med og uden ukrudtsharvning i vintersæd om foråret i samspil med forskellige dyrkningsfaktorer. *18. Danske Planteværnskonference. DJF-rapport nr. 40 (2001), 211-225***.**

Melander B. & Rasmussen K. (2000). Reducing intrarow weed numbers in row crops by means of a biennial cultivation system. *Weed Research, 40(2), 205-218*

Melander B., Cirujeda A. & Jørgensen M.H. (2003). Effects of inter-row hoeing and fertiliser placement on weed growth and yield of winter wheat. *Weed Research, 43(6), 428-438.*

Melander B., Holst N., Jensen P.K., Hansen E.M. & Olesen J.E. (2008). *Apera spica-venti* population dynamics and impact on crop yield as affected by tillage, crop rotation, location and herbicide programmes. *Weed Research, 48(1), 48-57.*

Olsen J, Kristensen L. & Weiner J. (2005). Effects of density and spatial pattern of winter wheat on suppression of different weed species. Weed Science 53**(**5), 690-694

Teasdale JR, Brandsæter LO, Calegari A. & Skora Neto F. (2007). *Cover crops and Weed Management*. Non-Chemical Weed Management: Principles, Concepts and Technology, (Editors: M.K. Upadhyaya & R. E. Blackshaw). CAB International (www.cabi.org), Wallingford (UK), 49-64.

Weeds – UK, results and experiences

Pest in crop Black-grass (*Alopecurus myosuroides*) in winter cereals		
Factor	**Description**	**Source**
Resistance genes	Evolved herbicide resistance now present in many European countries, particularly in the UK but increasing in France, Germany and other countries too. Enhanced metabolism widespread, but also ACCase and ALS target site resistance. Reduced availability of herbicides will increase resistance issues.	MOSS, S.R. (2004). Herbicide-resistant weeds in Europe: the wider implications. *Communications in Agricultural and Applied Biological Sciences (University of Gent, Belgium)* **69 (3)**, 3-11.
Previous crop Frequency in rotation	Greatly favoured by autumn sown crops. The trend to more autumn sown crops is largely responsible for the increases in black-grass.	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly Review* **38**, 170-191.
Sowing date	Favoured by early drilling, as a greater proportion of plants then come up in the crop, rather than pre drilling when they could be more easily destroyed. Delaying sowing until spring should help greatly but difficult on heavy soils and fewer herbicides available in spring crops.	MOSS, S.R. (1985). The effect of drilling date, pre-drilling cultivations and herbicides on *Alopecurus myosuroides* (black-grass) populations in winter cereals. In: *Proceedings of the Association of Applied Biologists Aspects of Applied Biology* **9**: *Conference on the Biology and Control of Weeds in Cereals* 31-39.

Tillage	Greatly favoured by non-inversion tillage unless high levels of control can be achieved. More uniform germination with minimum tillage can potentially improve control by herbicides. Herbicide resistance increases faster in non-inversion tillage. Increase in surface soil organic matter after prolonged minimum tillage can potentially reduced activity of residual herbicides.	POLLARD, F., MOSS, S.R., CUSSANS, G.W. & FROUD-WILLIAMS, R.J. (1982). The influence of tillage on the weed flora in a succession of winter wheat crops on a clay loam soil and a silt loam soil. *Weed Research* **22**, 129-136. MOSS, S.R. (1979). The influence of tillage and method of straw disposal on the survival and growth of black-grass, *Alopecurus myosuroides*, and its control by chlortoluron and isoproturon. *Annals of Applied Biology* **94**, 212-126.
Debris	May reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Not relevant.	
Nitrogen amounts	Very tolerant of a wide range of N, but certainly responds positively to increasing N fertilizer levels. Relative response of black-grass v cereal to increasing N levels is difficult to define.	MOSS, S.R., STORKEY, J., CUSSANS, J, PERRYMAN, S.A.M. & HEWITT, M.V. (2004). The Broadbalk long-term experiment at Rothamsted: what has it told us about weeds? *Weed Science* **52**, 864-873.
Nitrogen strategy	Manipulating N level as a weed control strategy is not a realistic option.	

Crop density Row spacing	Crop density has a moderate effect on black-grass. Low cereal densities (<120 plants/m2) are especially vulnerable. Above 250 cereal plants/m2, little additional reduction in black-grass. Crop density largely effects heads per plant, and hence seed return, rather than weed plant density. Narrow row spacing potentially reduced black-grass, but to a limited degree compared with spacings of 12.5 cm. Wider spacings likely to be much more vulnerable to black-grass.	MOSS, S.R. (1985). The influence of crop variety and seed rate on *Alopecurus myosuroides* competition in winter cereals. In: *Proceedings of the 1985 British Crop Protection Conference - Weeds* 701-708.
Margins management	Not particularly relevant as black-grass not a dominant species in field margins.	
Landscape	Not relevant	
Soil type	Favoured by heavy soils or on lighter soils with impeded drainage. Rarely a problem on sandy soils.	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly Review* **38**, 170-191.
Climate?	Favoured by cool temperate winter conditions, as occur in western Europe. Discouraged by colder winter conditions, as in central and eastern Europe and Scandinavia. Debatable whether recent increase in southern Sweden is due to milder winter conditions (global warming?) or more intensive cropping.	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly Review* **38**, 170-191.

Pest in crop Rye-grass (*Lolium spp.*) in winter cereals		
Factor	**Description**	**Source**
Resistance genes	Evolved herbicide resistance now present in many European countries. Enhanced metabolism widespread, but also to a lesser extent ACCase and ALS target site resistance. Reduced availability of herbicides will increase resistance issues.	COCKER, K.M., NORTHCROFT, D. S., COLEMAN, J.O.D. & MOSS, S.R. (2001). Resistance to ACCase inhibiting herbicides and isoproturon in UK populations of *Lolium multiflorum*: mechanisms of resistance and implications for control. *Pest Management Science* **57**, 587-597. ALARCON-REVERTE, R. & MOSS, S.R. (2008). Resistance to ACCase-inhibiting herbicides in the weed *Lolium multiflorum*. *Communications in Agricultural and Applied Biological Sciences (University of Gent, Belgium)* **73 (4)**, 899-902.
Previous crop Frequency in rotation	Favoured by autumn sown crops. The trend to more autumn sown crops is largely responsible for the increases in rye-grass. Rye-grass is a major forage grass and hence is sown very widely on stock farms but may become a major weed in arable crops. However, most cases in UK at least are on all-arable farms where no rye-grass has been sown for 25+ years.	MOSS, S.R., HORSEWELL, J., FROUD-WILLIAMS, R.J. & NDOPING, M.M. (1993). Implications of herbicide resistant *Lolium multiflorum* (Italian ryegrass). In: *Proceedings of the Association of Applied Biologists Aspects of*

		Applied Biology **35**: *Conference on Volunteer Crops as Weeds* 53-60.
Sowing date	Favoured by early drilling, as a greater proportion of plants then come up in the crop, rather than pre drilling when they could be more easily destroyed. Delaying sowing until spring should help greatly but difficult on heavy soils and fewer herbicides available in spring crops.	
Tillage	Favoured by non-inversion tillage unless high levels of control can be achieved. More uniform germination with minimum tillage can potentially improve control by herbicides. Herbicide resistance increases faster in non-inversion tillage. Increase in surface soil organic matter after prolonged minimum tillage can potentially reduced activity of residual herbicides.	MOSS, S.R. (2005). Managing herbicide-resistant rye-grass. In: *42nd Annual review of Weed Control*, 40-47. British Crop Protection Council.
Debris	May reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Rye-grass volunteers from grassland phase can be source of weed infestation in arable phase of rotation on mixed farms.	ORSON, J. & MOSS, S. R. (2007). Effective, sustainable Italian rye-grass control in winter cereals. *HGCA Topic sheet 100.* 2pp.
Nitrogen amounts	Certainly responds positively to increasing N fertilizer levels. Relative response of rye-grass v cereal to increasing N levels is difficult to define.	
Nitrogen strategy	Manipulating N level as a weed control strategy is not a realistic option.	
Crop density Row spacing	Crop density has a moderate effect on rye-grass. Low cereal densities (<120 plants/m2) are especially vulnerable. Above 250 cereal plants/m2, little additional reduction in rye-grass. Crop density largely effects heads per plant, and hence seed return, rather than weed plant density. Narrow row spacing potentially reduced rye-grass, but to a limited degree compared with spacings of 12.5 cm. Wider spacings likely to be much more vulnerable to rye-grass.	ALARCON-REVERTE, R. & MOSS, S. R. (2007). The agro-ecology of Italian rye-grass (*Lolium multiflorum*) as a weed of arable crops. In: *Proceedings of the 14th European Weed Research Society Symposium, Hamar, Norway*, 164.
Margins management	Sowing rye-grass for grass margins has potential to act as source for rye-grass as	ORSON, J. & MOSS, S. R.

	a weed in the cropped area.	(2007). Effective, sustainable Italian rye-grass control in winter cereals. *HGCA Topic sheet 100.* 2pp.
Landscape	Not relevant	
Soil type	Grows on a wide range of soils.	
Climate?	Different species favoured by different climates. Italian rye-grass (*Lolium multiflorum*) favoured by cooler temperate conditions (e.g. UK), whereas Rigid rye-grass (*Lolium rigidum*) favoured by hotter conditions (absent from UK).	

Pest in crop: Broad-leaved weeds Cleavers (*Galium aparine*), Chickweed (*Stellaria media*), Poppy (*Papaver rhoeas*), Scentless mayweed (*Tripleurospermum inodorum*) in winter cereals		
Factor	**Description**	**Source**
Resistance genes	Evolved ALS target site herbicide resistance now present in poppy in several countries (e,g. UK, Spain, Italy Greece) and in chickweed and mayweed at a lesser frequency. Lack of enhanced metabolism resistance and wider availability of effective alternatives means that resistance in broad-leaved weeds less of an issue than in grass-weeds, but reduced availability of herbicides will increase resistance issues.	MARSHALL, R., MOSS, S. R. & TATNELL, L. (2009). Control of ALS-resistant chickweed and poppy in cereals. *HGCA Information Sheet Topic 06.* 2pp.
Previous crop Frequency in rotation	Cleavers is definitely favoured by autumn sown cropping; the other species to a lesser degree.	
Sowing date	Much less influential with broad-leaved weeds compared with annual grasses.	
Tillage	In contrast to annual grass weeds, broad-leaved weeds tend to be favoured by ploughing. Non-inversion tillage tends to lead to fewer broad-leaved weeds, but more grass weeds.	
Debris	May reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Not relevant.	
Nitrogen amounts	Cleavers and chickweed responds positively to increasing N fertilizer levels.	

	These four species are major weeds largely due to their ability to continue to compete with the crop at high N levels. Many other annual broad-leaved weeds greatly discouraged by increasing N fertilizer.	
Nitrogen strategy	Reducing N level likely to increase the impact of many broad-leaved weeds.	
Crop density Row spacing	Crop density has a moderate effect on broad-leaved weeds competition. Narrow row spacing potentially reduced broad-leaved weeds impact. Wider spacings likely to be much more vulnerable, although may permit mechanical weed control which is more effective against broad-leaved than grass-weeds.	
Margins management	Margins can potentially act as source of infestation for some broad-leaved weeds (eg cleavers) but other species are adapted to disturbed habitats (cultivated fields) and so do not flourish in field margins.	
Landscape	Not relevant.	
Soil type	Cleavers and chickweed favoured by moisture retentive soils. Other two species less soil specific.	
Climate?	Cleavers and chickweed favoured by cooler temperate conditions (e.g. UK). Other two species less specific.	

Pest in crop: Common couch (*Elymus repens*) in winter cereals		
Factor	**Description**	**Source**
Resistance genes	No evolved herbicide resistance found anywhere worldwide in this species, probably because it is primarily a perennial. Clonal differences in response to herbicides likely, but little researched.	
Previous crop Frequency in rotation	In past couch was favoured by autumn sown cropping due to reduced time available for cultural control. Use of glyphosate has eliminated couch as a major weed problem in cereals.	
Sowing date	Mainly a factor in relation to application date of glyphosate.	
Tillage	Greatly favoured by non-inversion tillage, especially direct drilling.	POLLARD, F., MOSS, S.R., CUSSANS, G.W. & FROUD-WILLIAMS, R.J. (1982). The influence of tillage on the weed flora in a succession of winter

		wheat crops on a clay loam soil and a silt loam soil. *Weed Research* **22**, 129-136.
Debris	May reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Not relevant.	
Nitrogen amounts	Increased nitrogen tends to favour cereals and helps suppress couch to some degree.	
Nitrogen strategy	Manipulating N level as a weed control strategy is not a realistic option.	
Crop density Row spacing	Crop density has a moderate effect on couch. Narrow row spacing potentially reduce competition from couch. Wider spacings likely to be much more vulnerable.	
Margins management	Margins can act as source of infestation for couch.	
Landscape	Not relevant.	
Soil type	Couch favoured by moisture retentive soils.	
Climate?	Couch favoured by cooler temperate conditions (e.g. UK).	

Pest in crop Black-grass (*Alopecurus myosuroides*) in winter oilseed rape		
Factor	**Description**	**Source**
Resistance genes	Evolved herbicide resistance now present in many European countries, Enhanced metabolism widespread, but also ACCase and ALS target site resistance. Oilseed rape plays a key role in the management of resistant black-grass in a rotation, as several herbicides used in this crop are unaffected by resistance (propyzamide, carbetamide, metazachlor)	MOSS, S.R. (2004). Herbicide-resistant weeds in Europe: the wider implications. *Communications in Agricultural and Applied Biological Sciences (University of Gent, Belgium)* **69 (3)**, 3-11.
Previous crop Frequency in rotation	Greatly favoured by autumn sown crops. The trend to more autumn sown crops is largely responsible for the increases in black-grass. Oilseed rape generally follows a winter cereal and thus infestations in the rape are driven by seeds shed in this previous cereal	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly*

		Review **38**, 170-191.
Sowing date	Early sowing tends to favour the growth of the crop. Thus weed competition is lower in crops sown in August and early September. Later sown crops are less vigorous and more vulnerable to competition from grass weeds (including *A. myosuroides*)	LUTMAN, P.J.W. & DIXON, F.L. (1990) The competitive effects of volunteer barley (*Hordeum vulgare*) on the growth of oilseed rape (*Brassica napus*). *Annals of Applied Biology*, **117**, 633-644.
Tillage	Black-grass is favoured by non inversion tillage and direct drilling and reduced by ploughing. However, in oilseed rape the impact of tillage on crop establishment is equally significant. Thus a well established direct drilled crop can be much more suppressive of grass weeds than a less well established crop after ploughing.	POLLARD, F., MOSS, S.R., CUSSANS, G.W. & FROUD-WILLIAMS, R.J. (1982). The influence of tillage on the weed flora in a succession of winter wheat crops on a clay loam soil and a silt loam soil. *Weed Research* **22**, 129-136.
Debris	May reduce crop establishment, thus reducing the ability of the crop to suppress weeds. May also reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Not relevant.	
Nitrogen amounts	Black-grass is very tolerant of a wide range of N, but certainly responds positively to increasing N fertilizer levels. There is still debate as to whether autumn nitrogen improves the rape crop's competitive ability.	
Nitrogen strategy	Manipulating N treatments as a weed control strategy is not a realistic option.	
Crop density Row spacing	The ability of oilseed rape to branch and thus compensate for low crop density is well-known. Populations of 40 plants/m^2 can yield as well as 150 plant/m^2. Consequently, increasing crop density has only a marginal effect on the competitive impact of weeds. Crop densities have to be extremely low (<20 plants/m^2) before the weeds (including black-grass) benefit from the increased space.	
Margins management	Not particularly relevant as black-grass not a dominant species in field margins.	

Landscape	Not relevant	
Soil type	Favoured by heavy soils, or on lighter soils with impeded drainage. Rarely a problem on sandy soils.	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly Review* **38**, 170-191.
Climate?	Favoured by cool temperate winter conditions, as occur in western Europe. Discouraged by colder winter conditions, as in central and eastern Europe and Scandinavia. Debatable whether recent increase in southern Sweden is due to milder winter conditions (global warming?) or more intensive cropping.	MOSS, S.R. (1980). The agro-ecology and control of black-grass, *Alopecurus myosuroides* Huds., in modern cereal growth systems. *ADAS Quarterly Review* **38**, 170-191.

Pest in crop: volunteer cereals in winter oilseed rape		
Factor	**Description**	**Source**
Resistance genes	Volunteer cereals are susceptible to all the main grass weed herbicides used in oilseed rape	
Previous crop Frequency in rotation	The presence of volunteer cereals in rape depends on the presence of seeds shed from the previous cereal crop	
Sowing date	Early sowing tends to favour the growth of the crop. Thus weed competition is lower in crops sown in August and early September. Later sown crops are less vigorous and more vulnerable to competition from volunteer cereals	LUTMAN, P.J.W. & DIXON, F.L. (1990) The competitive effects of volunteer barley (*Hordeum vulgare*) on the growth of oilseed rape (*Brassica napus*). *Annals of Applied Biology*, **117**, 633-644.

Tillage	This weed is promoted by non-inversion tillage and especially direct drilling. Volunteer cereals are not a problem if land is ploughed prior to sowing rape.	
Debris	May reduce crop establishment, thus reducing the ability of the crop to suppress weeds.	
Volunteers	n/a	
Nitrogen amounts	Both rape and volunteer cereals respond positively to increasing N fertilizer levels, so N cannot be used to tip the balance in favour of the crop.	
Nitrogen strategy	Manipulating N level as a weed control strategy is not a realistic option.	
Crop density Row spacing	The ability of oilseed rape to branch and thus compensate for low crop density is well-known. Populations of 40 plants/m^2 can yield as well as 150 plant/m^2. Consequently, increasing crop density has only a marginal effect on the competitive impact of weeds. Crop densities have to be extremely low (<20 plants/m^2) before the weeds (including vol. cereals) benefit from the increased space.	
Margins management	Not relevant as volunteer cereals arise from seed shed from the previous crop	
Landscape	Not relevant	
Soil type	Present on all soils	
Climate?		

Pest in crop: Broad-leaved weeds Cleavers (*Galium aparine*), Chickweed (*Stellaria media*), Poppy (*Papaver rhoeas*), Scentless mayweed (*Tripleurospermum inodorum*) and Charlock (*Sinapis arvensis)* in winter oilseed rape		
Factor	**Description**	**Source**
Resistance genes	Resistance is not yet an issue in relation to the control of the major broad-leaved weeds in rape.	
Previous crop Frequency in rotation	All these species are common in autumn-sown crops. Charlock is particularly difficult to control in rape and so the weed tends to increase if rape is sown too frequently.	
Sowing date	As with the grass weeds, early-sown rape tends to be more competitive against broad-leaved species, though the evidence of this from research is equivocal	LUTMAN, P.J.W, BOWERMAN, P., PALMER,

		G.M. & WHYTOCK, G.P. (2000) Response of oilseed rape to interference from *Stellaria media*. *Weed Research*, **40**, 255-270. LUTMAN, P.J.W, BOWERMAN, P., PALMER, G.M. & WHYTOCK, G.P. (1993) The competitive effects of broad-leaved weeds in winter oilseed rape. *Proceedings 1993 Brighton Crop Protection Conference (Weeds)*, 1023-1028.
Tillage	Non-inversion tillage tends to lead to fewer broad-leaved weeds, but effects are not as clear cut as they are for annual grasses. Variations in seed persistence and germination response to light impact on the response of these broad-leaved weeds to cultivation.	
Debris	May reduce activity of herbicides due to interception, but only in extreme cases. May also impact on seed germination	
Volunteers	Not relevant.	
Nitrogen amounts	Cleavers and chickweed respond positively to increasing N fertilizer levels but so does the crop. The other species are less responsive. Nitrogen use does not have a major effect on the competitive impact of these weeds.	
Nitrogen strategy		
Crop density Row spacing	The ability of oilseed rape to branch and thus compensate for a low crop density is well-known. Populations of 40 plants/m^2 can yield as well as 150 plant/m^2. Consequently, increasing crop density has only a marginal effect on the competitive impact of broad-leaved weeds.	LUTMAN, P.J.W, BOWERMAN, P., PALMER, G.M. & WHYTOCK, G.P. (1993) The competitive effects of broad-leaved weeds in winter oilseed rape. *Proceedings 1993 Brighton Crop Protection Conference (Weeds)*, 1023-1028.

Margins management	Margins can potentially act as source of infestation for some broad-leaved weeds (eg cleavers) but it is not relevant to most as the margin habitat is not suited to their biology.	
Landscape	Not relevant.	
Soil type	Cleavers and chickweed favoured by moisture retentive soils. Other two species less soil specific.	
Climate?	Severe winters are effective in killing charlock. So milder winters arising from climate change would result in greater survival and more competition from this weed. Cleavers are most competitive as the crop matures in July and so particularly dry summers will reduce the effects of this weed.	LUTMAN, P.J.W, BOWERMAN, P., PALMER, G.M. & WHYTOCK, G.P. (1995) A comparison of the competitive effects of eleven weed species on the growth and yield of oilseed rape. *Proceedings 1995 Brighton Crop Protection Conference (Weeds)*, 877-882.

Pest in crop: Common couch (*Elymus repens*) in winter oilseed rape		
Factor	**Description**	**Source**
Resistance genes	No evolved herbicide resistance found anywhere worldwide in this species, probably because it is primarily a perennial. Clonal differences in response to herbicides likely, but little researched.	
Previous crop Frequency in rotation	In past couch was favoured by autumn sown cropping due to reduced time available for cultural control. Use of glyphosate has eliminated couch as a major weed problem in cereals.	
Sowing date	Mainly a factor in relation to application date of glyphosate.	
Tillage	Greatly favoured by non-inversion tillage, especially direct drilling.	
Debris	May reduce activity of herbicides due to interception, but only in extreme cases.	
Volunteers	Not relevant.	
Nitrogen amounts	Increased nitrogen tends to favour oilseed rape and helps suppress couch to some	

	degree.	
Nitrogen strategy	Manipulating N level as a weed control strategy is not a realistic option.	
Crop density Row spacing	The ability of oilseed rape to branch and thus compensate for a low crop density is well-known. Populations of 40 plants/m^2 can yield as well as 150 plant/m^2. Consequently, increasing crop density has only a marginal effect on the competitive impact of common couch.	
Margins management	Margins can act as source of infestation for couch.	
Landscape	Not relevant.	
Soil type	Couch favoured by moisture retentive soils.	
Climate?	Couch favoured by cooler temperate conditions (e.g. UK).	

Appendix C, cultural practises impact on pest, disease and weeds: Cereal pests

Denmark

Deroceras agreste or D. reticulatum (Slugs) in Cereals (In DK: Snegle)		
Factor		**Source**
Resistance genes	Not relevant for the Danish farmers	
Previous crop Frequency in rotation	The frequency of cereals is of little importance. If the previous crop has a moist microclimate, the slug population will increase.	
Sowing date	Late sowing increases the risk of attack. This is because an early sown crop is more established when the attack occurs.	
Tillage	Inverting tillage has a great reducing impact on the slug population. The longer the soil is “black” after harvest of the previous crop and before sowing, the more slugs are killed. If the tillage is followed by harrowing, it is possible to keep the slugs stressed and at the same time reduce the amount of available food. On heavy clay soils, reduced tillage may reduce slug problems, because the loose soil it leaves is a poorer habitat for the slugs.	
Debris	By removing debris, it is easier to dry out the soil, whereby the slugs are killed. At the same time the food supply is kept at a minimum.	

Volunteers	Not of particular importance	
Nitrogen amounts	Healthy plants are more likely to survive an attack of slugs than stressed plants	
Nitrogen strategy	Follow the general guidelines for fertilization during the growing season.	
Crop density Row spacing	Not of practical importance as a control option	
Landscape	In terms of slug problems, moisture is essential. Therefore avoid growing sensitive crops near forests, lakes, streams etc.	
Soil type	Slugs are mainly a problem on clay soils	
Climate?	As the slugs are dependent on moisture to survive, rainy periods promote the activity and therefore the risk of attack. They overwinter as eggs, but as the temperature increases, adults may also survive.	

Denmark

Oulema melanopus & O. lichenis (Cereal leaf beetle) in Cereals (In DK: Kornbladbille)		
Factor		**Source**
Resistance genes	No resistant varieties available to the Danish farmers.	
Previous crop Frequency in rotation	Not of particular importance	
Sowing date	Not of particular importance	
Tillage	Not of particular importance, as the beetle overwinters on trees and in forests surrounding the fields	
Debris	Not of particular importance	
Volunteers	Not of particular importance	
Nitrogen amounts	High nitrogen status promotes development of leaf beetles. With the nitrogen levels used in DK, this is however of little practical importance	Planteinfo
Nitrogen strategy	Follow the general guidelines for fertilization in the growing season	
Crop density Row spacing	Not of particular importance	
Landscape	In areas with large amount of overwintering places, there is an increased risk of early attack in the spring	
Soil type	Not of particular importance	
Climate?	At temperatures above 10°C the beetles start to emerge, if there is plenty of light. The egg laying does not start before the temperature reaches 19-20°C (warm and dry days)	Planteinfo

Denmark

Contarinia tritici & Sitodiplosis mosellana (lemon & orange wheat blossom midge) in Cereals (In DK: Gul hvedegalmyg & orangegul hvedegalmyg)		
Factor		**Source**
Resistance genes	There are wheat varieties on the Danish market, which are resistant towards the orange wheat blossom midge but not lemon blossom midge. These varieties contain certain types of organic acids in the grains, which are not palatable for the larvae. They therefore starve and dye.	Nielsen (2007)
Previous crop Frequency in rotation	As the larva overwinters in the soil, there is a higher risk of attack, if cereals are grown often. Wheat after wheat has been found to increase the population. The larvae are also able to remain in a dormant state for several years on the soil surface, meaning that in practise it is difficult to use the crop rotation for control purposes. The crops in the neighbouring fields are therefore of higher importance.	Nielsen (2007)
Sowing date	Not of particular importance	
Tillage	No clear data for the influence of tillage on the occurrence of lemon and orange wheat blossom midge. Some evidence however suggest that reduced tillage may promote the occurrence	
Debris	Not of particular importance	
Volunteers	Not of particular importance	
Nitrogen amounts	Healthy plants are more likely to withstand attack of the wheat blossom midge	
Nitrogen strategy	Follow the general guidelines for fertilization during the growing season	
Crop density Row spacing	Not of particular importance	
Landscape	Not of particular importance	
Soil type	Attacks have been observed on all soil types	
Climate?	As the wheat blossom midge is a fragile animal, windy and unfavourable weather conditions in general will inhibit large movements. Is it however sunny and calm weather, attacks are more likely to occur.	

Denmark

Rhopalosiphum padi, Sitobion avenae & Metopolophium dirhodum (aphids) in Cereals (In DK: Bladlus)		
Factor		**Source**
Resistance genes	There are no resistant varieties available to the Danish farmers.	
Previous crop Frequency in rotation	If the previous crop is a grass, and direct sowing is used, aphids may be a problem in the autumn, due to the risk of Barley Yellow Dwarf Virus (BYDV)	
Sowing date	The more the sowing of the winter cereals is delayed, the less risk there is for spread of BYDV	
Tillage	Inverting tillage and other actions removing the debris of monocots will reduce the risk of attack	
Debris	Not of particular importance, as the aphids only survive on living plants	
Volunteers	May be a problem as some aphids overwinter on grasses. It is therefore an advantage with some sort of stubble cultivation, as it removes the living places of the aphids	
Nitrogen amounts	A high nitrogen status favours the aphids, as the plant material stays green and therefore more attractive for a longer period. Due to the limitations on nitrogen use in Denmark, this is however of little importance.	Nielsen & Jensen (2001)
Nitrogen strategy	Follow the general guidelines and recommendations during the growing season, to avoid severe aphid attack	
Crop density Row spacing	Not of particular importance	
Landscape	Not of particular importance	
Soil type	Attacks of aphids occurs on all soiltypes	
Climate?	Aphids benefit from warm and dry conditions. At 15-20°C it takes 10 days to develop a generation. Lower temperatures and moist weather slows down the development, and heavy rain may even kill thousands of aphids. Strong winds and high temperatures also limits the development of the aphids.	

References:

Nielsen. G.C. (2007): *Flyvning af hvedegalmyg følges*, [Online]. Dansk Landbrugsrådgivning Landscentret, Planteproduktion. Skejby. [Cited on the 18th of March 2009]. Last revised 15th of May 2007. Available on the internet: <URL: http://www.lr.dk/planteavl/informationsserier/plantenyt/plnyt_2007-384.htm>

Nielsen, G. C. & J.P. Jensen (2001): *Markens sygdomme og skadedyr*. Dalum Landbrugsskoles Forlag. 21st edition, ISBN: 87-988336-1-8

Appendix C, cultural practises impact on pest, disease and weeds: Cereal pests

UK

BYDV transmission to winter wheat and winter barley by *Sitobion avenae* and *Rhopalosiphum padi*		
Factor	**Description**	**Source**
Resistance genes	Some cv are less susceptible to aphids but there is no true resistance.	
Previous crop Frequency in rotation	Aphids tend to be more abundant following an arable crop but previous crop has no influence on virus levels	(Foster *et al.*, 2004)
Sowing date	Early sowing likely lead to more virus transmission by cereal aphids on cereals (BYDV) [and by *Myzus persicae* on oilseed rape (BWYV)]. Late sowing dates may lead to more losses due to slugs.	(Foster *et al.*, 2004)
Tillage	Many pest problems may become worse with inversion tillage as many invertebrate predators and are damaged by ploughing. Direct drilling is likely to be of most benefit to predators. Direct drilling likely to be cause more virus transmission unless herbicide is used to control volunteers (see below).	(Stinner & House, 1990) (Holland, 2004)
Debris	Debris on or near the surface is likely to increase slug problems	(Stinner & House, 1990)
Volunteers	BYDV transmission is likely to be worse if volunteers provide a ‘green bridge’ between one year’s cereal crop and the next in the same field.	
Weeds	Virus levels are higher in weedy fields.	(Foster *et al.*, 2004)
Nitrogen amounts	Not a big problem. Too much nitrogen can lead to large aphid populations but also increased plant vigour. Other problems such as lodging are more important.	

Nitrogen strategy		
Crop density Row spacing	Reduced crop density is likely to lead increase the impact of slug damage. Increased crop density increases virus transmission in winter as aphids can walk between plants.	
Margin management	Diverse margins and beetle banks are likely to reduce aphid pest problems. Absence of hedges associated with more aphids.	(Foster *et al*., 2004)
Landscape	No simple relationship exists between aphid numbers, virus levels and landscape but a landscape with much non-arable land use, especially with grass (such as grazing), was often associated with more aphids but less clearly with virus.	(Foster *et al*., 2004)
Soil type	Soils with a high clay content are less favourable to both aphids and virus is less abundant on crops in clay soils, though not statistically significantly so.	(Foster *et al*., 2004)
Climate?	Warm winters and warm wet summers would increase the severity of aphid pests. Field aspect, latitude and proximity to the coast influence aphid abundance.	

UK

Orange wheat blossom midge in cereals		
Factor	**Description**	**Source**
Resistance genes	Resistance genes exist but not yet in bread-making wheats	
Previous crop Frequency in rotation	Problems likely to be worse in wheat following wheat as the pest overwinters in the soil.	
Sowing date		
Tillage	Minimum cultivation after cereal crop is likely to enhance survival of the pest but also to enhance survival of its parasitoid.	(Ferguson *et al*., 2007)
Debris	No data	
Volunteers	No data	
Nitrogen amounts	No data	
Nitrogen strategy	No data	
Crop density Row spacing	No data	
Margin management	No data	

Landscape	No specific data. Diverse landscapes are likely to reduce pest problems	
Soil type	No data. Likely to have an influence as the pest and its parasitoid both overwinter in the soil.	
Climate?		

UK

Slugs on winter wheat and winter barley		
Factor	**Description**	**Source**
Resistance genes	None	
Previous crop Frequency in rotation	Less risk after oilseed rape as there is less debris (see below).	
Sowing date	Late sowing dates are likely to lead to more losses due to slugs.	
Tillage	Slug problems may increase with reduced tillage.	(Holland, 2004; Stinner & House, 1990)
Debris	Debris on or near the surface is likely to increase slug problems	
Volunteers	No data	
Nitrogen amounts	No data	
Nitrogen strategy	No data	
Crop density Row spacing	Reduced crop density is likely to lead increase the impact of slug damage.	
Margin management	Diverse margins and beetle banks are likely to reduce slug problems as carabids are major predators of slugs.	
Landscape		
Soil type		

Climate?	Hotter, drier climates would reduce slug problems	

UK

Wheat bulb fly on winter wheat and winter barley		
Factor	**Description**	**Source**
Resistance genes		
Previous crop Frequency in rotation	Early-harvested crops or crops that leave bare soil exposed (potatoes, sugar beet, red beet and field vegetables) provide egg-laying sites and increase risk. Less of a risk when cereals following cereals.	http://www.hgca.com/minisite_manager.output/3158/3158/Knowledge%20Centre/Pest%20Management/Wheat%20Bulb%20Fly.mspx?minisiteId=11
Sowing date	Late sown or backward crops are more at risk.	http://www.hgca.com/document.aspx?fn=load&media_id=167&publicationId=276
Tillage		
Debris		
Volunteers		
Nitrogen amounts		
Nitrogen strategy		
Crop density Row spacing	Reduced tiller density increases the risk.	http://www.hgca.com/document.aspx?fn=load&media_id=167&publicationId=276
Margin management		
Landscape		

Soil type		
Climate?		

UK

References

Ferguson, A.W., Holdgate, R., Mason, N.S. & Williams, I.H. 2007. Non-inversion tillage to conserve functional biodiversity for biocontrol of oilseed rape pests., pp. 818-819 Proceedings of the XVI International Plant Protection Congress,15-18 October 2007., Vol. 2 The British Crop Production Council, Hampshire, UK., Glasgow, UK.

Foster, G.N., Blake, S., Tones, S.J., Barker, I. & Harrington, R. 2004: Occurrence of barley yellow dwarf virus in autumn-sown cereal crops in the United Kingdom in relation to field characteristics. Pest Manag. Sci. 60:113-125.

Holland, J.M. 2004: The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ. 103:1-25.

Stinner, B.R. & House, G.J. 1990: Arthropods and other invertebrates in conservation-tillage agriculture. Annu. Rev. Entomol. 35:299-318.

Appendix C, cultural practises impact on pest, disease and weeds: oilseed rape pests

All countries

***Psylliodes chrysocephala* (UK: cabbage stem flea beetle; DK: rapsjordloppe; FR: altise d'hiver du colza) in oilseed rape**		
Factor		**Source**
Resistance genes	There are no cultivars available with resistance towards the cabbage stem flea beetle	
Previous crop Frequency in rotation	No data	
Sowing date	Earlier-sown crops tend to suffer more severe cabbage stem flea beetle damage in the UK and Denmark probably because there are a limited number of early-emerging crops available and it is warmer so that beetles are more active. By contrast, early-sown organic crops but tended to suffer less damage in France.	Oversigten (2008) http://www.hgca.com/document.aspx?fn=load&media_id=168&publicationId=276 (Valantin-Morison *et al*., 2007)

Tillage	Shallow tillage reduced damage in organic crops in France and infestation in Germany. Studies in Canada with different species of flea beetle support this. Minimum cultivation after oilseed rape enhances survival of parasitoid wasps.	(Dosdall *et al.*, 1999; Ulber & Schierbaum-Schickler, 2003; Valantin-Morison *et al.*, 2007) (Klingenberg & Ulber, 1994)
Debris	Stubble and debris reduced infestation in Germany.	(Ulber & Schierbaum-Schickler, 2003)
Volunteers	No data	
Nitrogen amounts	In conventionally managed crops in Austria there was no influence of nitrogen rates from 45-125 kg/ha. In organic crops in France (soil N levels 54-335 kg/ha), infestation was greater in crops grown in soils with more nitrogen.	(Zaller *et al.*, 2008a; Zaller *et al.*, 2008b) (Valantin-Morison *et al.*, 2007)
Nitrogen strategy	No data	
Margin management	No data	
Crop density Row spacing	In organic crops in France, infestation was less in crops sown at higher densities. Studies in Canada with different species of flea beetle supported this in two out of three years.	(Valantin-Morison *et al.*, 2007) (Dosdall *et al.*, 1999)
Landscape	In organic crops in France, regions with a higher proportion of OSR in the landscape were less infested. In organic crops in France, some evidence for increased infestation in less woody landscapes.	(Valantin-Morison *et al.*, 2007) (Valantin-Morison *et al.*, 2007)
Soil type	No data	
Climate?	The beetles are capable to survive at low temperatures during the winter. Moisture has proved to be of importance to the development of the beetles. In the spring and summer, the activity of the beetles is favoured by higher temperatures.	Planteinfo

All countries

Phyllotreta spp. (cabbage flea beetles; FR: altises des cruciferes / petites altises) in oilseed rape. More frequent in France in recent years; not considered a pest of winter oilseed rape in the UK		
Factor	**Description**	**Source**
Resistance genes	None	
Previous crop Frequency in rotation	More risk to spring oilseed rape crops if winter oilseed rape is present.	
Sowing date	More risk with early sowings of winter oilseed rape	CETIOM
Tillage	No data	
Debris	No data	
Volunteers	No data	
Nitrogen amounts	No data	
Nitrogen strategy	No data	
Crop density Row spacing	No data	
Margins management	Most damage is around the field margin but no data on effect of margin management	
Landscape	No data	
Soil type	No data	
Climate?	No data	

All countries

Meligethes aeneus (UK: pollen beetle; DK: glimmerbøsse; FR: méligèthes des crucifères) in oilseed rape		
Factor		**Source**
Resistance genes	No resistance genes identified. Varietal associations and restored hybrids may be more vulnerable to this pest, losing more yield because male fertile plants are attacked and cross pollination is reduced.	http://www.hgca.com/document.aspx?fn=load&media_id=168&publicationId=276
Previous crop Frequency in rotation	In Austria, no effect of previous crop on pollen beetle infestation.	(Zaller *et al.*, 2008a)
Sowing date	Backward crops suffer more damage in the UK. (Late-sown crops may be backward in	http://www.hgca.com/document.

	the spring if they suffer slug, frost or pigeon damage)	aspx?fn=load&media_id=168&publicationId=276
Tillage	Minimum cultivation after oilseed rape enhances survival of parasitoid wasps.	http://www.hgca.com/document.aspx?fn=load&media_id=168&publicationId=276 (Ferguson *et al.*, 2007; Klingenberg & Ulber, 1994; Nilsson, 1985; Nitzsche & Ulber, 1998)
Debris	No data, unlikely to have an effect.	
Volunteers	No data. Early-flowering volunteers may attract pollen beetles. This could increase or reduce damage to crop plants.	
Nitrogen amounts	Healthy plants with good growth are generally more tolerant of attack, why it is important that the plants have a good supply of nutrients Low levels of nitrogen are likely to reduce ability to compensate for pollen beetle damage, as indicated by studies on organic crops in France (soil N levels 54-335 kg/ha) In conventionally managed crops in Austria there was no influence of nitrogen rates from 45-125 kg/ha.	(Nilsson 1994; Valantin-Morison *et al.*, 2007) (Zaller *et al.*, 2008a; Zaller *et al.*, 2008b)
Nitrogen strategy		
Crop density Row spacing	Low plant densities are less susceptible in conventionally-grown crops in France. With the increase of plant density the bud stage during which plants are susceptible to pollen beetle is longer. Branching of the flowering raceme is less and so there is less opportunity for compensation. By contrast, in organic fields in France, high plant density was associated with lower crop damage. In Austria there was no effect of crop density.	CETIOM trial in 2005 (Valantin-Morison *et al.*, 2007) (Zaller *et al.*, 2008a)
Margin management	In Germany old field margins were associated with increased rates of parasitism by parasitoids. In Switzerland, the same effect was associated with wild flower strips.	(Thies & Tscharntke, 1999; Buchi, 2002)
Landscape	In Germany pollen beetle activity was negatively correlated with landscape complexity	(Thies *et al.*, 2003)

	(% non crop area) and parasitism rates were positively correlated with landscape complexity but unrelated to % oilseed rape crop area. By contrast, in Austria, the abundance of pollen beetles was positively related to % non-crop area (and to woody areas) and negatively to % oilseed rape area. These differences may be due to methodological differences and differences in non-crop landscape composition.	(Zaller *et al*., 2008b)
Soil type	In Austria pollen beetles were more abundant in crops grown on soils with higher yield potential.	(Zaller *et al*., 2008b)
Climate?	No data. The relative phenology of pollen beetles and flowering is critical. If beetles emerge from overwintering earlier relative to the development of the inflorescence, arriving on the crop at bud stage, the pest will become more serious. Beetles start immigrating to crops when the temperatures reach 13-15°C in the spring.	

All countries

***Ceutorhynchus obstrictus*, syn. *C. assimilis* (UK: cabbage seed weevil; DK: skulpesnudebille; FR: charançon des siliques)**		
Factor		**Source**
Resistance genes	No genes identified	
Previous crop Frequency in rotation	No data	
Sowing date	The seed weevil becomes active at the start of flowering of winter oilseed rape. For this reason, in Denmark spring sown oilseed rape is attacked to a lesser extent than winter oilseed rape.	
Tillage	No data. Seed weevil parasitoids do not overwinter in the soil.	
Debris	Unlikely to have any influence	
Volunteers	No data	
Nitrogen amounts	A well established crop will always tolerate a more severe attack compared to a stressed crop (DK)	
Nitrogen strategy	Follow the general guidelines to assure optimal nutrient status of the crop (DK)	

Crop density Row spacing	No data	
Margin management	No data	
Landscape	The weevil overwinters in leaf litter in hedges, woodland boundaries etc. As the weevil is very mobile, local changes to the landscape may not influence infestation (DK).	(Dmoch & Klimek, 1975)
Soil type	No data	
Climate?	No data. Spring flight threshold is a little higher than pollen beetle	

All countries

***Ceutorhynchus napi* (rape winter stem weevil; FR: Charançon de la tige du colza); *Ceutorhynchus pallidactylus* (cabbage stem weevil; FR: Charançon de la tige du chou) in oilseed rape. NB: not significant UK pests**		
Factor	**Description**	**Source**
Resistance genes	No genes identified	
Previous crop Frequency in rotation	In Austria, no effect of previous crop on stem weevil infestation.	(Zaller *et al*., 2008a)
Sowing date	In organic fields in France, later sowing dates were associated with increased damage.	(Valantin-Morison *et al*., 2007)
Tillage	Minimum cultivation after oilseed rape enhances survival of parasitoid wasps.	(Ferguson *et al*., 2007; Klingenberg & Ulber, 1994)
Debris	No data	
Volunteers	No data	
Nitrogen amounts	In organic fields in France (soil N levels 54-335 kg/ha), increased soil nitrogen was associated with reduced damage.	(Valantin-Morison *et al*., 2007)
Nitrogen strategy	There is some evidence that increased nitrogen increases infestation in Croatia. In conventionally managed crops in Austria there was no influence of nitrogen rates from 45-125 kg/ha.	(Culjak *et al*., 2009) (Zaller *et al*., 2008a; Zaller *et al*., 2008b)
Crop density Row spacing	In organic fields in France, higher plant density was associated with reduced damage. In conventionally grown crops in France there was more damage to crops sown at	(Valantin-Morison *et al*., 2007) CETIOM

	high densities	
Margin management	No data	
Landscape	No clear relationship between infestation and the proportion of land under OSR in organic fields in France. Stem weevil abundance was negatively related to the proportion of land under OSR in Austria (is this a newer OSR-growing area? parasitism rates were low.) Stem weevil abundance was positively related to the degree of isolation from other OSR fields in Austria. No clear effect of the degree of woodiness of the landscape in organic fields in France. In Austria, stem weevil infestations increased with increased woodland in the landscape.	(Valantin-Morison *et al*., 2007) (Zaller *et al*., 2008b) (Zaller *et al*., 2008b) (Valantin-Morison *et al*., 2007) (Zaller *et al*., 2008b)
Soil type	In Austria stem weevils were more abundant in crops grown on soils with higher yield capacity	(Zaller *et al*., 2008a)
Climate?	More injurious in dry years	CETIOM

All countries

Dasineura brassicae **(UK: brassica pod midge; DK: skulpegalmyg; FR: cécidomyie des siliques) in oilseed rape**		
Factor		**Source**
Resistance genes	No genes identified	
Previous crop Frequency in rotation	In Austria, there was no effect of previous crop on infestation. However, brassica pod midge overwinters in the soil beneath the crop, therefore repeated oilseed rape crops or short rotations including oilseed rape are likely to exacerbate this pest.	(Zaller *et al*., 2008a) (Alford *et al*., 2003)
Sowing date	No data	
Tillage	Minimum cultivation after oilseed rape enhances survival of a parasitoid wasp but also enhances survival of the pest.	(Ferguson *et al*., 2007)
Debris	No data	
Volunteers	No data	
Nitrogen amounts	In conventionally managed crops in Austria there was no influence of nitrogen	(Zaller *et al*., 2008a; Zaller *et*

	rates from 45-125 kg/ha. A well established crop will always tolerate a more severe attack compared to a stressed crop (DK)	*al*., 2008b)
Nitrogen strategy	No data	
Crop density Row spacing	In Austria no effect of crop density.	(Zaller *et al*., 2008a)
Margin management	Often insecticide treatment of the edge of the crop is enough as this insect is very edge-distributed	CETIOM
Landscape	In Austria, pod midge infestations increased with increased woodland and landscape diversity. The pod midge is a rather fragile animal, which may only able to fly over short distances.	(Zaller *et al*., 2008b)
Soil type	Moist soils promote the hatching of the pod midge (DK)	
Climate?	There are 3 generations of the pod midge every year in DK and UK, two on winter rape and one on spring rape.	

All countries

***Deroceras agreste* or *D. Reticulatum* (UK: slugs; DK: agersnegle; FR: limace) in oilseed rape**		
Factor		**Source**
Resistance genes	No resistance genes	
Previous crop Frequency in rotation	The frequency of oilseed rape is of little importance, as long as a proper crop rotation is used. If the previous crop has a moist microclimate, the slug population will increase.	
Sowing date	The longer the soil is crop free before sowing, the more slugs are killed. This is however difficult to manage in practical farming, as there is too little time between harvest of the previous crop and sowing of winter oilseed rape.	
Tillage	Inversion tillage reduces slug populations. If the tillage is followed by harrowing, it is possible to keep the slugs stressed and at the same time reduce the amount of available food.	
Debris	By removing debris, it is easier to dry out the soil, whereby the slugs are killed. At the same time the food supply is kept at a minimum.	
Volunteers	Not of particular importance	

Nitrogen amounts	Healthy plants are more likely to survive pest attacks	
Nitrogen strategy	No data	
Crop density Row spacing	Crops sown at low densities are at greater risk	
Landscape	Moisture is essential to slugs. Therefore avoid growing sensitive crops near forests, lakes, streams etc (DK)	
Soil type	Slugs are more a problematic on clay soils	
Climate?	Wet weather promotes slug survival and activity and therefore the risk of attack. In DK they overwinter as eggs, but as the temperature increases, adults may also survive, as they do in UK.	

France

Delia radicum **(cabbage root fly; FR: mouche du chou) in oilseed rape**		
Factor	**Description**	**Source**
Sowing date	Much more frequent in early sowings	CETIOM

France

Brevicoryne brassicae **(cabbage aphid; FR: puceron cendré du chou) in oilseed rape:**	
Factor	**Description**
Insecticide	Pyrethroid-resistant cabbage aphids exist in France.

Oilseed rape insect pests, all countries: References

Alford, D., Nilsson, C. & Ulber, B. 2003. Insect Pests of Oilseed Rape Crops. In: D. Alford (ed.) Biocontrol of Oilseed Rape Pests, 1 ed. Blackwell Publishing, Oxford: 9-42.

Buchi, R. 2002: Mortality of pollen beetle (*Meligethes* spp.) larvae due to predators and parasitoids in rape fields and the effect of conservation strips. Agric. Ecosyst. Environ. 90:255-263.

Culjak *et al*., 2009, IOBC WPRS Bulletin (in press)
Dmoch, J. & Klimek, G. 1975: Badania nad pasozytami chowacza podobnika (*Ceuthorrynchus assimilis* Payk.). III. Obserwacje nad biologia *Trichomalus perfectus* (Walker). Roczniki nauk Rolniczych, Seria E 5:125-136.
Dosdall, L.M., Dolinski, M.G., Cowle, N.T. & Conway, P.M. 1999: The effect of tillage regime, row spacing, and seeding rate on feeding damage by flea beetles, Phyllotreta spp. (Coleoptera: Chrysomelidae), in canola in central Alberta, Canada. Crop Prot. 18:217-224.
Ferguson, A.W., Holdgate, R., Mason, N.S. & Williams, I.H. 2007. Non-inversion tillage to conserve functional biodiversity for biocontrol of oilseed rape pests., pp. 818-819 Proceedings of the XVI International Plant Protection Congress,15-18 October 2007., Vol. 2 The British Crop Production Council, Hampshire, UK., Glasgow, UK.
Giamoustaris A. & R. Mithen (1997): Glucosinolates and disease resistance in oilseed rape (*Brassica napus* ssp. *oleifera*). *Plant pathology*. Vol. 46, PP: 271-275.
Klingenberg, A. & Ulber, B. 1994: Untersuchungen zum Auftreten der Tersilochinae (Hym., Ichneumonidae) als Larvalparasitoide einiger Rapschadlinge im Raum Gottingen 1990 und 1991 und zu deren Schlupfabundanz nach unterschiedlicher Bodenbearbeitung. J. Appl. Entomol. 117:287-299.
Nielsen, G. C. & J.P. Jensen (2001): *Markens sygdomme og skadedyr*. Dalum Landbrugsskoles Forlag. 21st edition, ISBN: 87-988336-1-8
Nilsson, C. 1985: Impact of plowing on emergence of pollen beetle parasitoids after hibernation. Zeitschrift Fur Angewandte Entomologie (Journal of Applied Entomology) 100:302-308.
Nilsson, C. 1994: Pollen beetles (Meligethes spp.) in oil seed rape crops (Brassica napus L.): biological interactions and crop losses Swedish University of Agricultural Sciences, Alnarp.

Nitzsche, O. & Ulber, B. 1998: Influence of different tillage treatments following the harvest of oilseed-rape on the mortality of pollen beetle (Meligethes spp.) parasitoids. Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz-Journal of Plant Diseases and Protection 105:417-421.
Nyvall R.F. (1999): *Field crop diseases*. 3rd edition, Blackwell publishing, ISBN: 0-8138-2079-0, 9780813820798, the UK.
Thies, C. & Tscharntke, T. 1999: Landscape structure and biological control in agroecosystems. Science 285:893-895.
Thies, C., Steffan-Dewenter, I. & Tscharntke, T. 2003: Effects of landscape context on herbivory and parasitism at different spatial scales. Oikos 101:18-25.
Ulber, B. & Schierbaum-Schickler, C. 2003. The effect of tillage regime on the infestation of oilseed rape by the cabbage stem flea beetle, *Psylliodes chrysocephala*., pp. 1037 11th International Rapeseed Congress, Vol. 3, Copenhagen.
Valantin-Morison, M., Meynard, J.M. & Dore, T. 2007: Effects of crop management and surrounding field environment on insect incidence in organic winter oilseed rape (Brassica napus L.). Crop Prot. 26:1108-1120.
Zaller, J.G., Moser, D., Drapela, T., Schmoeger, C. & Frank, T. 2008a: Effect of within-field and landscape factors on insect damage in winter oilseed rape. Agric. Ecosyst. Environ. 123:233-238.

Zaller, J.G., Moser, D., Drapela, T., Schmoger, C. & Frank, T. 2008b: Insect pests in winter oilseed rape affected by field and landscape characteristics. Basic Appl. Ecol. 9:682-690.

Diseases in barley – all countries

Fusarium head blight		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, but differences are less clear compared with wheat.	Bai G 2004
Previous crop Frequency in rotation	Maize as previous crop has been found to increase the risk of fusarium head blight. Wheat has also been found to potentially increase the risk in some regions.	
Sowing date	Not found to be of specific importance	
Tillage	Ploughing decreases the risk by removing inoculum. Minimal tillage significantly increases the risk when cereal follows maize.	
Debris	Crop debris on the surface increases the risk of disease development.	
Volunteers	No information available.	
Nitrogen amounts	Literature describes the risk to increase following high N –levels. Practical importance unclear.	
Nitrogen strategy	No information available.	
Crop density Row spacing	No information available	
Landscape	No information available	
Soil type	No information available	
Climate	Wet and humid conditions during heading and flowering stimulate attack (GS 51-69)	

Powdery Mildew in barley		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Many specific genes are used and described but also non-specific resistance genes are known to be of importance, In particular cultivars with Mlo resistance genes have given stable degrees of resistance.	
Previous crop	If volunteers have been removed the impact is small	
Sowing date	Early sowing is known to increase disease level in autumn, but this rarely have impact on disease levels in spring. Late sowing in the autumn has been seen to increase disease level in spring, as the very young plants in spring generally are more susceptible than early sown crops.	
Tillage	Ploughing has been found to increase the risk of mildew compared with minimal tillage. It is the increased mineralization of nitrogen following ploughing, which stimulates a more severe attack.	
Debris and volunteers	Debris does not directly influence disease levels as mildew is an obligate parasite. Fields with volunteers are an important source of inoculum as it serves as a green bridge for the spread of the disease between seasons. Historically winter barley was banned in some countries in order to minimize the risk of mildew in spring barley.	
Nitrogen amounts	High nitrogen use increases the susceptibility of the crop due to higher N concentration in leaves, easier penetration of the fungus. Possibly also due to denser crop with higher levels of humidity, which stimulates the epidemic.	Jensen & Munk
Nitrogen strategy	Spilt strategies of N are less likely to encourage high disease levels compared to single applications of a single high level	
Crop density	High crop density stimulates mildew development as the humidity in the crop favours disease development. Overlapping in headlands often have higher levels of attack.	
Landscape	The attacks are known to be more severe near hedges and in low and humid parts (black soils) of the field.	
Soil type	Sandy soils are known to stimulate the disease development. This is often related to manganese deficiency which makes the crop more prone to mildew, It might also be related to the crop being more exposed to stress on these soils or higher levels of leaf wetness due to higher differences between plant and soil temperatures. Stress in the form of drought can also increase the risk of mildew.	
Climate	As temperatures rise in the spring, dormant mycelium starts to grow and spores are quickly produced. The disease is not very temperature dependant although 15 C is optimal with relative humidity above 95%. Free water inhibits spore germination. Under dry conditions	

	spores can be formed in about seven days.	

Rhynchosporium in barley		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Specific genes are known and described.	
Previous crop	If the previous crop was barley the risk is increased	
Seed born	The disease is seedborne. So seed treated or healthy seed is important.	
Sowing date	Early sowing increase the risk as more lifecyclus can be going on.	
Tillage	Ploughing has been found to decrease the risk of rhynchosporium as it helps to remove inocullum compared with minimal tillage..	
Debris and volunteers	Debris may directly influence disease levels as conidie spores are released from crop debris in the autumn. Volunteers may also act as a source of inoculum.	
Nitrogen amounts	High nitrogen amounts increase to some extend the susceptibility of the crop. The effect is not believed to be of major importance within commercially used rates	Jenkyn & Griffiths (1978)
Nitrogen strategy	No information available	
Crop density	No information available	
Landscape	No specific information is known	
Soil type	No specific information is known	
Climate	Dry weather reduces the risk as the disease needs humidty to stimulate development, preferably during 2 days. Optimal temperatures are 15-25 C. Attack developing between first node and heading are most yield reducing.	

Net blotch in barley		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Specific genes are known and described.	
Previous crop	If the previous crop was barley the risk is increased	
Seed born	The disease is seedborne. So seed treated or healthy seed is important.	
Sowing date	No information available	
Tillage	Ploughing has been found to decrease the risk of rhynchosporium as it helps to remove inoculum compared with minimal tillage..	
Debris and volunteers	Debris may directly influence disease levels as conidie spores are released from crop debris in the autumn. Volunteers may also act as a source of inoculum.	
Nitrogen amounts	High nitrogen amounts increase to some extend the susceptibility of the crop. The effect is not believed to be of major importance within commercially used rates	
Nitrogen strategy	No information available	
Crop density	No information available	
Landscape	No specific information is known	
Soil type	No specific information is known	
Climate	Dry weather reduces the risk as the disease needs humidity to stimulate development. Optimal temperatures are 15-20 C. Attack developing between first node and heading are most yield reducing.	

Eyespot in barley		
Factor	**Description**	**Source**
Resistance genes	No specific information about resistance available in barley. The problems in spring barley are small and not relevant but the disease can occur in winter barley.	
Previous crop	Wheat and other cereals increases the risk for attack. Non-cereal crops such as oilseed rape, etc reduce the risk	
Sowing date	Early sowing is known to increase disease risk. Late sowing is seen to decrease the disease level as epidemic generally gets delayed.	
Tillage	Ploughing can increase the risk – thought to be due to increased N-mineralization coupled with deeper drilling. Direct drilling can reduce disease levels as plants have a more open habit with greater air movement. Ploughing can preserve crop debris and then increase the risk once it is brought back to the surface.	
Debris and volunteers	Debris may directly influence disease levels as disease as both ascospores and condiospores are released from crop debris in the autumn.	
Nitrogen amounts	High nitrogen amounts increase to some extent the susceptibility of the crop.	
Nitrogen strategy	No information available	
Crop density	High crop density stimulates development as the humidity increases in a dense crop stand.	
Landscape	No specific information is known	
Soil type	No specific differences seen	
Climate	Dry weather reduces the risk as the disease particularly during elongation the crop as the crop escape the attack by fast growth. Infection occurs at temperatures above 5 C and during wet periods.	Clark *et al.*

Brown rust in barley		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Many specific genes are used and described but also non-specific resistance genes are known to be of importance	Das *et al*. 2007.
Previous crop	High proportions of susceptible varieties and infected barley crops in the previous year increases the risk of attack as high levels of inoculum potentially can survive to the next season.	
Sowing date	Early sowing is known to increase disease level in autumn. Late sowing in the autumn has been seen to increase disease level in spring, as the very young plants in spring generally are more susceptible than early sown crops.	
Tillage	No information available.	
Debris and volunteers	Debris does not directly influence disease levels as mildew is an obligate parasite. Fields with volunteers are an important source of inoculum as it serves as a green bridge for the spread of the disease between seasons.	
Nitrogen amounts	High nitrogen amounts increase the susceptibility of the crop due to high nitrogen concentrations in leaf tissues, easier penetration in plants and possibly due to denser crop with higher levels of humidity.	
Nitrogen strategy	No information available	
Crop density	No information available.	
Landscape	No information available.	
Soil type	No information available.	
Climate	Severe frosts during the winter will reduce the inoculum and help to reduce disease levels. However, within plants the fungus can survive at very low temperatures. In the spring in mild weather the fungus starts to grow and produces active sporulating lesions. Temperature at 15-22 C and relative humidity of 100% are optimal for spore germination, penetration and production of new spores. The disease is most common in warm summers	

DasMK; Griffey,CA,Baldwin BD;Waldenmaier, CM. Vaughn,ME,Price AM & Brookes. 2007. Host resistance and fungicide control of Brown rust,in barley and effect on grain yield and yield components. Crop Protection v ol. 26, 1422-1430.

<u>Diseases in wheat – all countries</u>

Fusarium head blight		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and may help to reduce disease levels. Several non-specific genes are used and described e.g. *Fhb1* from Chinese spring wheat. Different types of resistance are described: Resistance to initial infection (type I), resistance to pathogen (type II), ability to degrade mycotoxins (type III and IV), or resistance to grain infection (type V). Tall cultivars are often seen to be less susceptible (longer distance for inoculum to spread). Stak and compact heads are known to increase the risk of attack. Open flowering increase the risk of infection.	Bai G 2004 Buerstmayr *et al*. 2009 Hilton *et al*. 1999, Skinnes *et al*. 2008 Parry *et al.*, 1995 ; Mesterhazy, 1999 ; Bushnell *et al.*, 2003
Previous crop Frequency in rotation	Maize as previous crop has been found to increase the risk of fusarium head blight. Wheat has also been found to potentially increase the risk in some regions.	Data from DAAS Parry *et al.*, 1995
Sowing date	Not found to be of specific importance	
Tillage	Ploughing decreases the risk by removing inoculum. Minimal tillage significantly increases the risk when wheat follows maize or wheat.	Bateman *et al*. 2007 McMullen *et al.*, 1997
Debris	Crop debris on the surface increases the risk of disease development.	Jørgensen & Olsen, 2007 Bateman *et al*. 2007 Xu 2003; Parry *et al.*, 1995 ; Shaner, 2003
Volunteers	No information available.	
Nitrogen amounts	Literature describes the risk to increase following high N –levels. Practical importance unclear.	Heier *et al*. 2005 Lemmens *et al*. 2004 Champeil *et al.*, 2004
Nitrogen strategy	No information available.	
Crop density Row spacing	No information available	Data from DAAS
Landscape	No information available	
Soil type	No information available	

Climate	Wet and humid conditions during heading and flowering stimulate attack (GS 51-69)	Xu 2003; Parry *et al.*, 1995

Powdery Mildew in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Many specific genes are used and described but also non-specific resistance genes are known to be of importance	Xiu-Qiang Huang[1] 2004 Lillemo *et al*. 2008
Previous crop	If volunteers have been removed the impact is small	
Sowing date	Early sowing is known to increase disease level in autumn, but this rarely have impact on disease levels in spring. Late sowing in the autumn has been seen to increase disease level in spring, as the very young plants in spring generally are more susceptible than early sown crops.	Data from DAAS Jørgensen *et al*. 1997
Tillage	Ploughing has been found to increase the risk of mildew compared with minimal tillage. It is the increased mineralization of nitrogen following ploughing, which stimulates a more severe attack.	Jørgensen & Olsen (2006)
Debris and volunteers	Debris does not directly influence disease levels as mildew is an obligate parasite. Fields with volunteers are an important source of inoculum as it serves as a green bridge for the spread of the disease between seasons.	
Nitrogen amounts	High nitrogen use increases the susceptibility of the crop due to higher N concentration in leaves, easier penetration of the fungus. Possibly also due to denser crop with higher levels of humidity, which stimulates the epidemic.	Olesen *et al*. 2003
Nitrogen strategy	Spilt strategies of N are less likely to encourage high disease levels compared to single applications of a single high level	Olesen *et al*. 2003
Crop density	High crop density stimulates mildew development as the humidity in the crop favours disease development. Overlapping in headlands often have higher levels of attack.	Jørgensen *et al*. 1997
Landscape	The attacks are known to be more severe near hedges and in low and humid parts (black soils) of the field.	Bjerre *et al*. 2006
Soil type	Sandy soils are known to stimulate the disease development. This is often related to manganese deficiency which makes the crop more prone to mildew, It might also be related to the crop being more exposed to stress on these soils or higher levels of leaf wetness due to higher differences between plant and soil temperatures. Stress in the form of drought can also increase the risk of mildew.	Data from DAAS
Climate	As temperatures rise in the spring, dormant mycelium starts to grow and spores are quickly	The encyclopaedia of cereal

	produced. The disease is not very temperature dependant although 15 C is optimal with relative humidity above 95%. Free water inhibits spore germination. Under dry conditions spores can be formed in about seven days.	diseases

Septoria in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Specific genes are known and described but also non-specific resistance genes are known to be of importance	Brown *et al*. 2001
Previous crop	High proportions of wheat in the crop rotation increase the proportion of inoculum and risk for attack. In areas with lots of wheat the level of ascospores will be high.	
Sowing date	Early sowing is known to increase disease level in autumn, which again can result in higher disease levels in spring and summer. Late sowing can decrease disease levels as the epidemic is generally delayed	Jørgensen *et al*. 1997
Tillage	Ploughing has been found to increase the risk of septoria compared with minimal tillage. This might be related to an increased N-mineralization following ploughing which can stimulate a more severe attack.	Jørgensen & Olsen (2006)
Debris and volunteers	Debris may directly influence disease levels as ascospores are released from crop debris in the autumn. Volunteers are not important as source of inoculum as they will typically be destroyed before the attack becomes visual.	
Nitrogen amounts	High nitrogen amounts increase to some extend the susceptibility of the crop. The effect is not believed to be of major importance within commercially used rates (120-200kg/ha).	Olesen *et al*. 2003
Nitrogen strategy	Spilt strategies have been seen to reduce the attack compared with single applications.	Olesen *et al*. 2003
Crop density	Low crop density stimulates septoria development as the disease is spread up the crop by rainsplash which is more effective in thinner crops. Dense crops may reduce rainsplash but have in some trials been found to increase the risk, possibly due to higher humidity in the crop.	Jørgensen *et al*. 1997
Landscape	No specific information is known	
Soil type	No specific information is known	
Climate	Dry weather reduces the risk as the disease needs 48 hours of humidty to stimulate development. Optimal temperatures are 15-20 C	The encyclopaedia of cereal diseases

Eyespot in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with moderate resistance genes are known, and help to reduce disease levels.	Murry *et al*. 1995 Hugguet Roberts *et al*. 2001
Previous crop	Wheat and other cereals increases the risk for attack. Non-cereal crops such as oilseed rape, etc reduce the risk	Schulz *et al*. 1990
Sowing date	Early sowing is known to increase disease risk. Late sowing is seen to decrease the disease level as epidemic generally gets delayed. When wheat is sown after wheat it is recommended if possible and practical to delay the sowing time to minimize the risk.	Schulz *et al*. 1990
Tillage	Ploughing can increase the risk – thought to be due to increased N-mineralization coupled with deeper drilling. Direct drilling can reduce disease levels as plants have a more open habit with greater air movement. Ploughing can preserve crop debris and then increase the risk once it is brought back to the surface.	Schulz *et al*. 1990
Debris and volunteers	Debris may directly influence disease levels as disease as both ascospores and condiospores are released from crop debris in the autumn.	
Nitrogen amounts	High nitrogen amounts increase to some extent the susceptibility of the crop.	
Nitrogen strategy	No information available	
Crop density	High crop density stimulates development as the humidity increases in a dense crop stand.	Jørgensen *et al*. 1997
Landscape	No specific information is known	
Soil type	No specific differences seen in some countries other see some differences.	Schulz *et al*. 1990
Climate	Dry weather reduces the risk as the disease particularly during elongation the crop as the crop escape the attack by fast growth. Infection occurs at temperatures above 5 C and during wet periods.	The encyclopaedia of cereal diseases

yellow rust in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Many specific genes are used and described but also non-specific resistance genes are known to be of importance	Hovmøller, 2007 Bariana *et al*. 2001 Singh *et al*. 2000
Previous crop	High proportions of susceptible varieties and infected wheat in the previous year increases the risk of attack as high levels of inoculum potentially can survive to the next season.	Gladders *et al*. 2007
Sowing date	Early sowing is known to increase disease level in autumn. Late sowing in the autumn has been seen to increase disease level in spring, as the very young plants in spring generally are more susceptible than early sown crops.	Gladders *et al*. 2007
Tillage	No information available.	
Debris and volunteers	Debris does not directly influence disease levels as mildew is an obligate parasite. Fields with volunteers are an important source of inoculum as it serves as a green bridge for the spread of the disease between seasons.	
Nitrogen amounts	High nitrogen amounts increase the susceptibility of the crop due to high nitrogen concentrations in leaf tissues, easier penetration in plants and possibly due to denser crop with higher levels of humidity.	Bryson *et al*. HGCA report
Nitrogen strategy	No information available	
Crop density	High crop density stimulates yellow rust development as the humidity in the crop increases disease development.	
Landscape	No information available.	
Soil type	No information available.	
Climate	Severe frosts during the winter will reduce the inoculum and help to reduce disease levels. However, within plants the fungus can survive at very low temperatures. In the spring in cool moist weather the fungus starts to grow and produces active sporulating lesions. Temperature at 10-15 C and relative humidity of 100% are optimal for spore germination, penetration and production of new spores.	Christensen, *et al*.1993 Gladders *et al*. 2007 The encyclopaedia of cereal diseases

Brown rust in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with good resistance are known, and help to reduce disease levels. Many specific genes are used and described but also non-specific resistance genes are known to be of importance	Singh *et al*. 2000
Previous crop	High proportions of susceptible varieties and infected wheat in the previous year increases the risk for attack as high levels of inoculum potentially can survive to the next season.	
Sowing date	Early sowing is known to increase disease level in autumn. Late sowing in the autumn has been seen to increase disease level in spring, as the very young plants in spring generally are more susceptible than early sown crops.	
Tillage	No information available.	
Debris and volunteers	Debris does not directly influence disease levels as mildew is an obligate parasite. Fields with volunteers are an important source of inoculum as it serves as a green bridge for the spread of the disease between seasons.	
Nitrogen amounts	High nitrogen amounts increase the susceptibility of the crop due to high N-content of leaves, easier penetration in plants grown at high N levels but also due to denser crop with higher levels of humidity, which favours the epidemic.	
Nitrogen strategy	No information available	
Crop density	Dense crops likely to favour the disease as higher levels of humidity favour the disease	
Landscape	No information available.	
Soil type	No information available.	
Climate	Severe frosts during the winter will reduce the inoculum and help to minimize the disease level. Mild winter and warm spring and summer weather stimulate attack. Temperatures between 15 and 22 C accompanied by 100% relative humidity are needed for sporulation and spore germination.	The encyclopaedia of cereal diseases

Tan spot in wheat		
Factor	**Description**	**Source**
Resistance genes	Varieties with moderate resistance are known, and help to reduce disease levels. Few specific genes are described for this disease.	Jørgensen & Olsen 2007
Previous crop	Wheat as previous crop increases the risk of attack as high levels of inoculum potentially can survive to the next season on debris	Jørgensen & Olsen 2007
Sowing date	No information available. Disease will in most regions in Europe first develop in spring as ascospores need to ripen and spread. This normally takes place in April.	
Tillage	Tillage is found to have a major impact on the disease. Increasing amounts of straw and debris increase the amount of inoculum. Ploughing will minimize the disease risk to a very low level.	Jørgensen & Olsen 2007 Jensen *et al*. 2001
Debris and volunteers	Debris from a previous crop of wheat left on the surface will increase the risk of tan spot as a source of inoculum for both ascospores and condiospores.	Jørgensen & Olsen 2007 Jensen *et al*. 2001
Nitrogen amounts	No information available.	
Nitrogen strategy	No information available	
Crop density	No information available	
Landscape	No information available.	
Soil type	No information available.	
Climate	Weather conditions which stimulate the breakdown of debris will help to reduce the inoculum. Warm and humid summers stimulate disease development. Optimum temperatures are between 20-28 C accompanied by long periods of dew or rain (18 hours or more)	The encyclopaedia of cereal diseases

Take all in wheat		
Factor	**Description**	**Source**
Resistance genes	There are no varieties with specific resistance genes. Different wheat varieties have been found to build up different amounts of take-all inoculum in the soil, when grown as first cereal crop.	Gutteridge *et al*. 2008
Previous crop	The disease is usually most severe in second, third or fourth successive cereal crops, but generally declines in importance in continuous cereals. Oats and broad leaved crops like oilseed rape as the previous crop will reduce the risk of take all.	Gutteridge *et al*. 2008 Cook 2003
Sowing date	Early sowing is known to increase disease risk. Late sowing is seen to decrease the disease level as the epidemic is delayed. When wheat is sown after wheat it is recommended to delay the sowing time to minimize the risk. A crop sown in ideal conditions is better than one where soil structure is poor.	Bødker *et al*. 1990. Schulz & Jørgensen 1993 Gutteridge *et al*. 1987
Tillage	Tillage is found sometimes to have a major impact on the disease development. Increased levels are sometimes seen following ploughing compared with non-inversion tillage, but sometimes the opposite can take place. It relates to factors like soil compaction, water content, etc. Light puffy seedbeds can encourage the development of the disease. In short sequences of cereals, ploughing generally has an advantage.	Gutteridge *et al*. 2008 Cook 2003
Debris and volunteers	Debris from a previous crop of wheat left in the field will increase the risk. Cereal volunteers and grasses can be carriers of the disease and e.g. make oil seed rape less effective as a break crop.	Gutteridge & Hornby 2003
Nitrogen amounts	Reduced levels of N can increase the risk of attack as the crop has limited sources to develop root systems. Ammonium sulphate consistently has given less disease compared with ammonium nitrate, urea and ammonium chloride fertilisers.	Gutteridge *et al*. 1987
Nitrogen strategy	Early applications of N in February/March, followed by the main dressing in April will help to reduce the severity on the roots.	Gutteridge *et al*. 2008
Crop density	No information available	
Landscape	No information available.	
Soil type	Take all causes most damage on light soils (Sand, Sandy loams and loams), particularly if they are alkaline in nature. Crops grown on more sandy soils are more likely to develop take all as plants are more likely to suffer from drought stress. Poor drainage increase risk.	Gutteridge *et al*. 2008
Climate	Weather conditions which stimulate disease development is warm and moist autumns and winters. Wet springs and dry summers.	The encyclopaedia of cereal diseases

References

Brown JKM, Kema GHJ, Forrer HR, Verstappen ECP, Arraiano LS, Brading PA, Foster EM, Fried PM, Jenny E (2001) Resistance of wheat cultivars and breeding lines to septoria tritici blotch caused by isolates of *Mycosphaerella graminicola* in field trials. Plant Pathol 50:325–38

Bariana HS, Hayden MJ, Ahmed NU, Bell JA, Sharp PJ, McIntosh RA (2001) Mapping of durable adult plant and seedling resistances to stripe rust and stem rust diseases in wheat. J Agric Res 52:1247–1255

Bateman, GL; R. J. Gutteridge, Y. Gherbawy, M. A. Thomset and P. Nicholson. 2007. Infection of stem bases and grains of winter wheat by *Fusarium culmorum* and *F. graminearum* and effects of tillage method and maize-stalk residues. Plant Pathology 56:, 604–615.

Bjerre, K. Jørgensen, LN & Olesen JE. (2006) Site-specific management of crop disease. In: Handbook of Precision Agriculture – Principles and Applications. Eds, A. Srinivasan. Food production press 207-251

Buerstmayr H., Ban T., Anderson J. 2009. QTL mapping and marker-assisted selection for *Fusarium* head blight resistance in wheat: a review. Plant Breeding 128, 1—26

Butteridge RJ Hammond-Kosack KE 2008 Strategies for the control of take all. BSPP Presidential meeting Cereal Pathosystems. London 75-87

Bødker, L., Schultz, H., & Kristensen, K. 1990. Influence of cultural practices on incidence of take-all (Gaeumannomyces graminis var tritici) in winter wheat and winter rye. Tidsskrift for Planteavl. **94**, 201-209.

Christensen, K., Jørgensen, L. N. og Secher, B. J. M. 1993. Udvikling af gulrustmodel ud fra historiske data. 10. Danske Planteværnskonference, Sygdomme og skadedyr. Tidskrift for Planteavls specialserie S 2237, 71-78.

Cook, RJ 2003. Take-all of wheat. Physiological and Molecular Plant Pathology 62: 73-86.

Gladders; Langton[1]; Barrie[2]; Hardwick[1]; Taylor[1]; Paveley[3] 2007 The importance of weather and agronomic factors for the overwinter survival of yellow rust (*Puccinia striiformis*) and subsequent disease risk in commercial wheat crops in England Annals of Applied Biology, Volume 150, Number 3, June 2007 , pp. 371-382(12)

Guihua Bai 2004 MANAGEMENT AND RESISTANCE IN WHEAT AND BARLEY TO FUSARIUM HEAD BLIGHT[1] Annual Review of Phytopathology Vol. 42: 135-161 (Volume publication date September 2004)

Gutteridge RJ & Hornby D 2003. Effects of sowing date and volunteers on the infectivity of soil infested with Gaeumannomyces graminis var. tritici and on take all disease in successive crops of winter wheat. Annals of Applied Biology. 143 275-282

Gutteridge RJ, Bateman GL Hornby D. 1987 Comparisons of the effects of spring applications of ammonium chlroidde and other nitrogen fertilizer on take all in winter wheat. Journal of Agricultural Science, Cambridge 108 567-572

Hilton, AJ; P. Jenkinson, T. W. Hollins and D. W. Parry. 1999. Relationship between cultivar height and severity of Fusarium ear blight in wheat. Plant Pathology 48: 202–208

Hovmøller M. 2007 Sources of seedling and adult plant resistance to Puccinia striiformis f.sp tritici in european wheats. Plant breeding 126, 225-233

Huguet-Robert V, Dedryver F, Roder MS, Korzun V, Abelard P, Tanguy AM, Jaudeau B, Jahier J. 2001. **Isolation of a chromosomally engineered durum wheat line carrying the *Aegilops ventricosa Pch1* gene for resistance to eyespot.**. Genome, 2001, 44:345-349. [abstract]

Jensen, KF, Jørgensen, LN, Henriksen L, Nielsen GC. 2001 Hvedebladplet – en ny svampe sygdom i Danmark. Grøn Viden Markbrug 232.

Jørgensen, LN, Olsen LV (2007) Control of tan spot (*Drechslera tritici-repentis*) using host resistance. Tillage methods and fungicides. Crop Protection, 26: 1606-1616.

Jørgensen, L.N. Secher B.J.M., Olesen J.E. Mortensen, J. 1997. Need for fungicide treatments when varying agricultural parameters. Aspect of Applied Biology, Optimizing cereal input: Its scientific basis. 50, 285-292.

Lillemo, M. B. Asalf, R. P. Singh, J. Huerta-Espino, X. M. Chen, Z. H. He, Å. Bjørnstad . 2008. The adult plant rust resistance loci Lr34/Yr18 and Lr46/Yr29 are important determinants of partial resistance to powderymildew in bread wheat line Saar . Theor Appl Genet 116:1155–1166.

Murray TD, de la Peña RC, Yildirim A, Jones SS 1994 **A new source of resistance to *Pseuudocercosporella herpotrichoides*, cause of eyespot disease of wheat, located on chromosome 4V of *Dasypyrum villosum***. Plant Breeding, 1994, 113:281-286. [abstract]

Olesen, J. E.; Jørgensen, L.N., Petersen, J. & Mortensen, J. (2003) Effects of rate and timing of nitrogen fertilizer on disease control by fungicides in winter wheat 1. Grain yield and foliar disease control Journal of Agricultural Sciences 140, 1-13.

Olesen, J. E.; Jørgensen, L.N., Petersen, J. & Mortensen, J.(2003) Effects of rate and timing of nitrogen fertilizer on disease control by fungicides in winter wheat 2. Crop growth and disease development. Journal of Agricultural Sciences, 140, 15-29.

Schultz, H., Bødker, L., Jørgensen, L.N. & Kristensen, *K.* 1990. Influence of different cultural practices on distribution and incidence of eyespot (*Pseudocercosporella herpotrichoides*) in winter rye and winter wheat. Tidsskrift for planteavl. **94**, 211-221.

Schulz, H. & Jørgensen, L. N. 1993. Influence of different cultural practices on distribution and incidence of eyespot in Denmark. In 'Exploring the depth of eyespot' ed. G. D. Palmer, Schering AG, Berlin

Singh RP, Huerta-Espino J, Rajaram S (2000) Achieving nearimmunity to leaf and stripe rusts in wheat by combining slow rusting resistance genes. Acta Phytopathol et Entomol Hungarica 35:133–139

Skinnes, H , Tarkegne, Y, Dieseth, JA, Bjornstad, A. 2008. Associations between anther extrusion and Fusarium Head Blight in European wheat. Cereal Research Communications 36 Suppl. B: 223-231

Xiangming Xu. 2003. Effects of Environmental Conditions on the Development of Fusarium Ear Blight. E.J. Plant Pathol. 109: 683-689.

Xiu-Qiang Huang[1]; Marion S. Röder[2] 2004 Molecular mapping of powdery mildew resistance genes in wheat: A review Euphytica, Volume 137, Number 2, May 2004 , pp. 203-223(21)

Cultural practices impact on diseases in oilseed rape

Phoma stem canker		
Factor	**Description**	**Source**
Resistance genes	Varieties with moderate to good resistance are known, and may help to reduce disease levels. Several specific genes have been used over the years are used and described but also non- specific resistance genes are known to be of importance. The *L. maculans* pathogen has become resistant to some specific genes. Tall cultivars are often seen to be more susceptible (through increased lodging risk).	(Delourme *et al*., 2006)
Previous crop Frequency in rotation	Frequency of OSR in rotation is a big issue since inoculum is generated from fruiting bodies that develop on the stem debris	(Rempel and Hall, 1993; West *et al*., 2001)
Sowing date	Some evidence that early sowing (and subsequent production of large plants) prevents the development of canker epidemics. Small plants certainly get hit harder.	(Sun *et al*., 2000)
Tillage	Ploughing decreases the risk by removing inoculum.	(West *et al*., 2001)
Debris	OSR crop debris on the surface increases the risk of disease development (even old debris which has been ploughed up).	(Rempel and Hall, 1993; West *et al*., 2001)
Volunteers	Not much information, may act as green bridge	
Nitrogen amounts	Literature describes the risk to increase following high N –levels since taller plants are more prone to lodging. Practical importance unclear.	No papers specifically on effect of N on disease
Nitrogen strategy	No information available.	
Crop density Row spacing	No specific information regarding canker	
Landscape	No information available	
Soil type	No information available	
Climate	Wet, warm summers initiate early epidemic onset since ascospores are released earlier when new season OSR plants are small. Severe cankers can result.	(Toscano-Underwood *et al*., 2003)

Light leaf spot		
Factor	**Description**	**Source**
Resistance genes	Varieties with moderate to good resistance are known, and may help to reduce disease levels. The underlying genetics that underpin resistance are not well understood	(Boys *et al*., 2007; Bradburne *et al*., 1999)
Previous crop	Frequency of OSR in rotation is a big issue since inoculum is generated from fruiting bodies that develop on the upper stem and pod debris of previous crop. However, this material decomposes quickly, so adjacent fields probably more of a problem unless growing OSR after OSR.	(Fitt *et al*., 1998; Gilles *et al*., 2001; Gilles *et al*., 2000)
Sowing date	Modelling of crop data indicated that soince light leaf spot is a polycyclic disease, early sowing increases risk considerably.	(Welham *et al*., 2004)
Tillage	Ploughing decreases the risk by removing inoculum.	(Turkington *et al*., 2000)
Debris and volunteers	OSR crop debris on the surface increases the risk of disease development. Volunteers have been implicated in carry-over of light leaf spot from season to season.	
Nitrogen amounts	Literature describes the risk to increase following high N –thicker canopies increase humidity and therefore risk from pod infection. Practical importance unclear	
Nitrogen strategy	?	
Crop density	No information available.	
Landscape	No specific information regarding canker	
Soil type	No information available	
Climate	Modelling suggests climate change, with increased temperature, light leaf spot will get less severe with the range of the disease shifting north.	Evans *et al*., unpublished.

Sclerotinia		
Factor	**Description**	**Source**
Resistance genes	Some differences between cultivars, but mechanism of resistance not understood. Generally controlled by one or two spring sprays.	(Gladders *et al*., 2009; Koch *et al*., 2007)
Previous crop	Rotation important as OSR not the only host for this pathogen. Sclerotia remain in the soil for some time, so OSR in close rotation also increases risk.	(Buntin *et al*., 2007)
Sowing date	Doesn't affect disease risk directly	
Tillage	Ploughing buries sclerotia, but they can survive for quite long periods. Non-till probably has little effect since sclerotial germination is controlled by environmental factors	(Koch *et al*., 2007; Sochting and Verreet, 2004)
Debris and volunteers	Sclerotia produced in debris, but volunteers not important	
Nitrogen amounts	No effect	(Koch *et al*., 2007)
Nitrogen strategy	No effect	
Crop density	Most reports no effect	(Koch *et al*., 2007)
Landscape	No effect reported between different slopes/aspects	(Kutcher *et al*., 2005)
Soil type	No effect reported	(Koch *et al*., 2007; Kutcher *et al*., 2005)
Climate	?	

References

Boys, E.F., Roques, S.E., Ashby, A.M., Evans, N., Latunde-Dada, A.O., Thomas, J.E., West, J.S., and Fitt, B.D.L. (2007) Resistance to infection by stealth: *Brassica napus* (winter oilseed rape) and *Pyrenopeziza brassicae* (light leaf spot). European Journal of Plant Pathology, 118, 307-321.

Bradburne, R., Majer, D., Magrath, R., Werner, C.P., Lewis, B., and Mithen, R. (1999) Winter oilseed rape with high levels of resistance to Pyrenopeziza brassicae derived from wild Brassica species. Plant Pathology, 48(4), 550-558.

Buntin, G.D., Cunfer, B.M., Phillips, D.V., and Wilson, J.P. (2007) Sequence and rotation effects on pest incidence and grain yield of double-cropped soybean and pearl millet after winter wheat and canola. Crop Management(October), 1023-1001.

Delourme, R., Chevre, A.M., Brun, H., Rouxel, T., Balesdent, M.H., Dias, J.S., Salisbury, P., Renard, M., and Rimmer, S.R. (2006) Major gene and polygenic resistance to *Leptosphaeria maculans* in oilseed rape (*Brassica napus*) European Journal of Plant Pathology, 114(1), 41-52.

Fitt, B.D.L., Doughty, K.J., Gilles, T., Gladders, P., Steed, J.M., Su, H., and Sutherland, K.G. (1998) Methods for assessment of light leaf spot (Pyrenopeziza brassicae) on winter oilseed rape (Brassica napus) in the UK. Annals of Applied Biology, 133(3), 329-341.

Gilles, T., Ashby, A.M., Fitt, B.D.L., and Cole, T. (2001) Development of Pyrenopeziza brassicae apothecia on agar and oilseed rape debris. Mycological Research, 105, 705-714.

Gilles, T., Evans, N., Fitt, B.D.L., and Jeger, M.J. (2000) Epidemiology in relation to methods for forecasting light leaf spot (Pyrenopeziza brassicae) severity on winter oilseed rape (Brassica napus) in the UK. European Journal of Plant Pathology, 106(7), 593-605.

Gladders, P., Oxley, S.J.P., Dyer, C., Ritchie, F., Smith, J.A., Roques, S., Moore, A., Maulden, K., and Torrance, J. (2009) New fungicides for oilseed rape: defining dose-response activity. HGCA Project Report(449), 103 pp.

Koch, S., Dunker, S., Kleinhenz, B., Rohrig, M., and von Tiedemann, A. (2007) Crop loss-related forecasting model for Sclerotinia stem rot in winter oilseed rape. Phytopathology, 97(9), 1186-1194.

Kutcher, H.R., Malhi, S.S., and Gill, K.S. (2005) Topography and management of nitrogen and fungicide affects diseases and productivity of canola. Agronomy Journal, 97(2), 533-541.

Rempel, C.B., and Hall, R. (1993) Dynamics of Production of Ascospores of Leptosphaeria-Maculans in Autumn on Stubble of the Current Years Crop of Spring Rapeseed. Canadian Journal of Plant Pathology-Revue Canadienne De Phytopathologie, 15(3), 182-184.

Sochting, H.P., and Verreet, J.A. (2004) Effects of different cultivation systems (soil management and nitrogen fertilization) on the epidemics of fungal diseases in oilseed rape (Brassica napus L. var. napus). Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz, 111(1), 1-29.

Sun, P., Fitt, B.D.L., Gladders, P., and Welham, S.J. (2000) Relationships between phoma leaf spot and development of stem canker (*Leptosphaeria maculans*) on winter oilseed rape (*Brassica napus*) in southern England. Annals of Applied Biology, 137, 113-125.

Toscano-Underwood, C., Huang, Y.J., Fitt, B.D.L., and Hall, A.M. (2003) Effects of temperature on maturation of pseudothecia of Leptosphaeria maculans and L-biglobosa on oilseed rape stem debris. Plant Pathology, 52(6), 726-736.

Turkington, T.K., Clayton, G.W., Klein-Gebbinck, H., and Woods, D.L. (2000) Residue decomposition and blackleg of canola: influence of tillage practices. Canadian Journal of Plant Pathology-Revue Canadienne De Phytopathologie, 22(2), 150-154.
Welham, S.J., Turner, J.A., Gladders, P., Fitt, B.D.L., Evans, N., and Baierl, A. (2004) Predicting light leaf spot (*Pyrenopeziza brassicae*) risk on winter oilseed rape (*Brassica napus*) in England and Wales, using survey, weather and crop information. Plant Pathology, 53(6), 713-724.
West, J.S., Kharbanda, P.D., Barbetti, M.J., and Fitt, B.D.L. (2001) Epidemiology and management of *Leptosphaeria maculans* (phoma stem canker) on oilseed rape in Australia, Canada and Europe. Plant Pathology, 50, 10-27.