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D2.3
IPM guidelines for winter wheat based rotations in Europe

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1. SUMMARY

Six on-station experiments and several on-farm experiments were conducted to test and validate innovative IPM solutions combining several IPM tools for winter wheat based rotations. The experiments showed that many non-chemical IPM tools provided effective control of weeds and diseases and could replace the use of pesticides but nonetheless the gross margin of the IPM systems were lower than that of the current practice (CP). Some IPM tools are ready for wider adoption by farmers (e.g. variety mixtures, inter-row cultivation and delayed sowing) whereas others need to be optimised. In conclusion, reducing the reliance on pesticides by combining IPM tools with a reduced input of pesticides seems to be way forward in winter wheat based rotations with the current state-of-art of alternative IPM tools but in the future pesticide use may be opted out with new and more effective alternative methods becoming available.

2. OBJECTIVES

The objective of WP2 was to test and validate innovative IPM solutions for important pests of winter wheat in winter wheat based rotations in Northern Europe where winter wheat is the most widely cultivated annual crop. A design-assessmentadjustment cycle was adopted. Initially pre-existing tools, strategies and tactics were combined to innovative IPM solutions but the intention was at a later stage to incorporate new knowledge and tools coming out of the research activities of WP8 – 11 into IPM2. Despite the fact that WP8-11 produced many interesting and very novel outcomes none of them were ready for implementation in large-scale field trials hence no major changes were made to the IPM solutions tested.

3. MATERIALS AND METHODS

3.1. Approach

Six multiyear on-station field experiments were conducted comparing the agronomic, economic and environmental performance of current practice (CP) and two IPM strategies (named IPM1 and IPM2, respectively) in winter-wheat based crop rotations. The experiments were conducted in Denmark, France (2 locations), Germany, Poland and Scotland. Figure 1 shows the location of the experiments.

Figure 1. Location of on-station experiments

The experiments in Denmark, Germany, Poland and Scotland were initiated as part of PURE and have only run for three years while the two French experiments were on-going experiments. The four experiments in Denmark, Germany, Poland and Scotland were 3-year rotations including only the three strategies. The French experiments had more treatments and current practice and the two IPM strategies were chosen among the treatments. In one of the French experiment advanced IPM was a 'no pesticide' scenario while in the other one it was an 'organic' scenario. Except for the German trial, crop rotation was part of the IPM strategies.

The main focus of the two IPM strategies was to reduce the dependence on herbicides and fungicides while less focus were devoted to insect pests and thus the use of insecticides as weeds and diseases are generally considered more important than insect pests in winter wheat based rotations in Northern Europe. The current practice represented what could be considered good agricultural practice in the country/region where the experiment was located. Compared to current practice IPM1 had a more diverse crop rotation (winter and spring annual crops), more use of preventive cultural practices, mechanical weed control measures and disease resistant varieties. In IPM2 further crop diversification (perennial crops), cover crops, more use of forecasting models and decision support system and innovative IPM tools such as elicitors was added to the list of IPM tools applied for IPM1. The crop rotations of the on-station experiments are shown in Table 1.

Table 1. Crop rotations of on-station experiments. WW=winter wheat, WOSR=winter oilseed rape, SB=spring barley, SO=spring oat, PEA=pea, M=maize, WB=winter barley, WDW=winter durum wheat, BW=buckwheat, SL=spring linseed, ALF=alfalfa, WFB=winter faba bean, SFB= spring faba bean, HE=hemp, TR=triticale.

	Current system	IPM1	IPM2
United Kingdom	WW-WW-WOSR	SB-WW-WOSR	PEA-WW-WOSR
Denmark	WOSR-WW-WW	WOSR-WW-SB	WOSR-WW-SO
Poland	WOSR-WW-WW	WOSR-WW-SB	WOSR-WW-SB
Germany	M-WW-WB	M-WW-WB	M-WW-WB
France (Arvalis)	PEA/WOSR-WDW-SB-WW	BW/SL-WDW-SB-WW	ALF-ALF-ALF-WW-SL-WFB-WW
France (INRA)	WOSR-WW-SFB-WW	WFB-WW-WOSR-WW-SB	SFB-WW-HE-TR-M-WW

One-year on-farm experiments were conducted in Denmark, France and Germany. In Denmark the on-farm experiments were established on the 5 demonstration farms that constitute the arable part of the Danish demonstration farm network. Focus of the experiments was on single IPM tools such as variety mixtures. In the French trials two management strategies (current versus IPM) was compared on 10 farms every year. In Germany, as in Denmark, the on-farm experiments were set up on farms belonging to the extensive German demonstration farm network. Five farms in

Northern Germany were chosen for the on-farm experiments. As in the French trials current and IPM strategies were compared focussing on e.g. the use of disease resistant varieties, weeds and disease monitoring and decision support systems. The overall objective of the German trials was to reduce the Treatment Frequency Index (TFI).

3.2. Pests

Any pest observed in the experiments was monitored but some pests were devoted more attention than others because they are considered more important. A variety of rotational crops was included in the experiments but for the sake of clarity only the results with pest of winter wheat are presented and discussed in this report.

In the winter wheat crop focus was on annual grass weeds such as silky bentgrass (*Apera spica-venti*), anaul ryegrass (*Lolium multiflorum*) and wild oat (*Avena fatua*) and broadleaved weeds such as cleavers (*Galium aparine*), cornflower (*Centaurus cyanum*) and mayweeds (*Matricaria sp*).

Among the diseases septoria (*Mycosphaerella graminicola*), yellow rust (*Puccinia striiformis*) and brown rust (*Puccinia recondite*) were devoted most interest. Disease pressure varied significantly between years and locations.

Figure 2.Most important diseases in winter wheat in the PURE experiments (left to right: septoria, yellow rust and brown rust).

4. Results

4.1. Technical results

In general weeds, diseases and pests were well controlled with current practice and IPM1 while unsatisfactory control was observed with the advanced IPM strategy in some years and at some locations. An example of unsatisfactory control was weed control in IPM2 in the German on-station experiment in 2011/12 and 2012/13 where weed harrowing was the control measure applied. In both years, and in particular in 2012/13, the effect on *Apera spica-venti* was low resulting in a significant yield loss. In 2013/14 weed harrowing was given up and replaced by chemical weed control using the decision support system DDS Herbicide.

In the two French trials unsatisfactory control of particular weeds was frequently observed in IPM2 due to the fact that pesticides were not applied.

IPM1 winter wheat yields were either comparable or lower than those of current practice while the IPM2 yields generally were lower than those of current practice (Figure 3). Highest yields were recorded in the UK in 2012/13. Yield losses were highest in the UK and in the French trial where IPM2 resembles an organic scenario (Arvalis). In some cases yield losses in IPM1 and IPM2 could most likely be attributed to the applied IPM measures, e.g. delayed sowing (IPM1 and 2 in Denmark in 2012/13), while in other cases it was caused by unsatisfactory pest control (IPM2 in 2011/12 in Denmark).

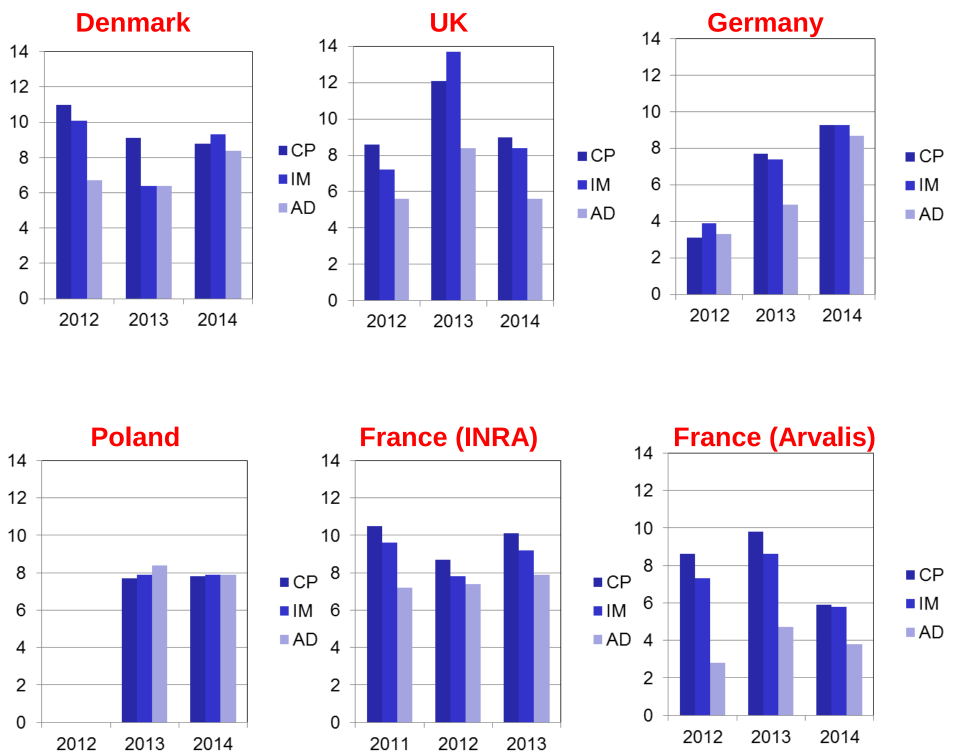

Figure 3. Winter wheat yields in the 6 on-station experiments. In 2011/12 the winter wheat crops did not survive the winter in Poland. In the German trial yields were unusually low in 2011/12 due to low soil fertility. IM=IPM1 and AD=IPM2.

Pesticide use was significantly reduced in both the intermediate and advanced IPM treatments compared to current practice (Figure 4). Reductions in pesticide use in the IPM1 system were more pronounced in Denmark and France than at the other locations. Next to the two French experiments where pesticides were opted out in IPM2 the greatest reduction in IPM2 was observed in Denmark.

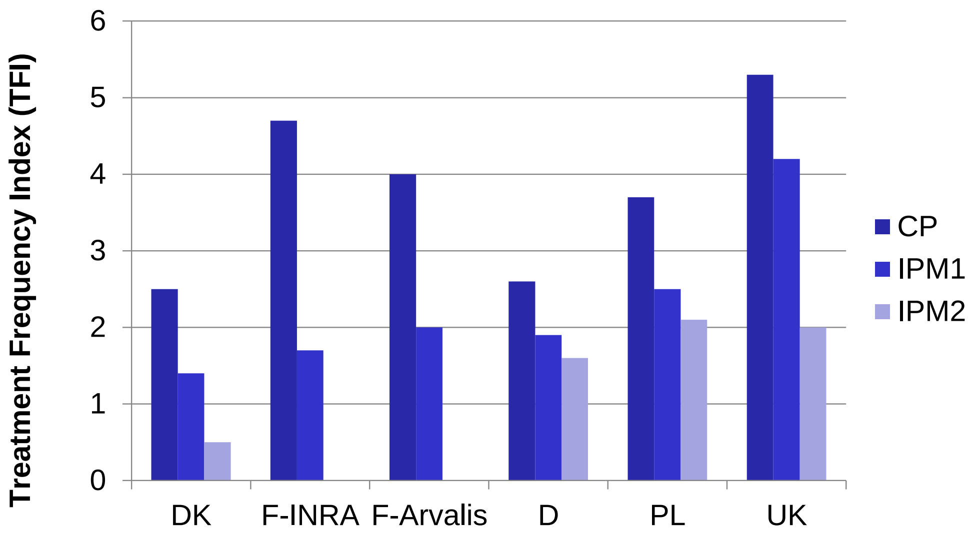

Figure 4. Pesticide use expressed as the Treatment Frequency Index (TFI). As the standard doses may vary between countries TFIs are not always directly comparable between countries.

4.2. Sustainability of IPM solutions

The economic sustainability was assessed through a cost benefit analysis while the environmental sustainability was assessed using DEXiPM, a multi-criteria tool for evaluating cropping systems, and SYNOPS.

The DEXiPM analyses are still ongoing for some of the on-station location. The results are available for the two French on-station experiments. In the Arvalis experiment overall sustainability was better of the IPM1 and IPM2 systems compared to CP (Figure 5). Concerning the environmental sustainability the ranking of the systems were IPM2>IPM1>CP while the economic sustainability of the IPM2 system was higher than that of the CP and IPM1 systems due to higher output prices on organic products. No differences were observed in social sustainability.

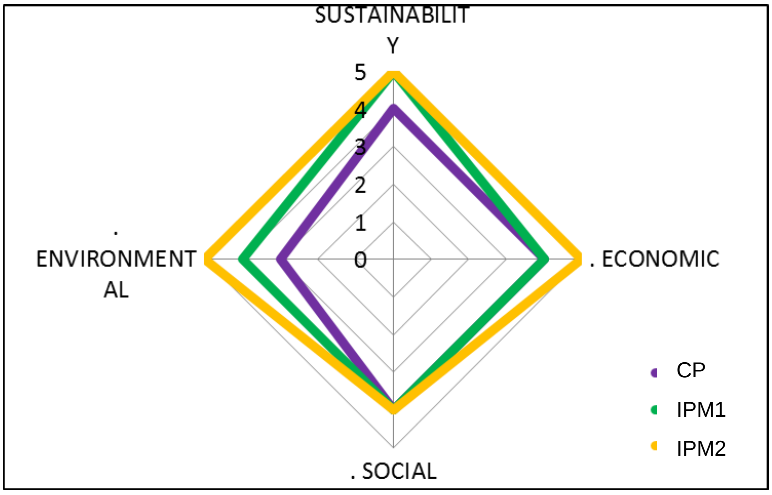

Figure 5. Schematic illustration of the outcome of the DEXiPM analyses of the Arvalis on-station experiment

DEXiPM analyses from INRA are shown in Figure 6. No differences were observed in overall sustainability although the environmental sustainability was higher for IPM2 than for IPM1 which was higher than CP. The improved environmental sustainability was negated by the lower economic sustainability. As was the case for the Arvalis experiment no differences were observed in social sustainability.

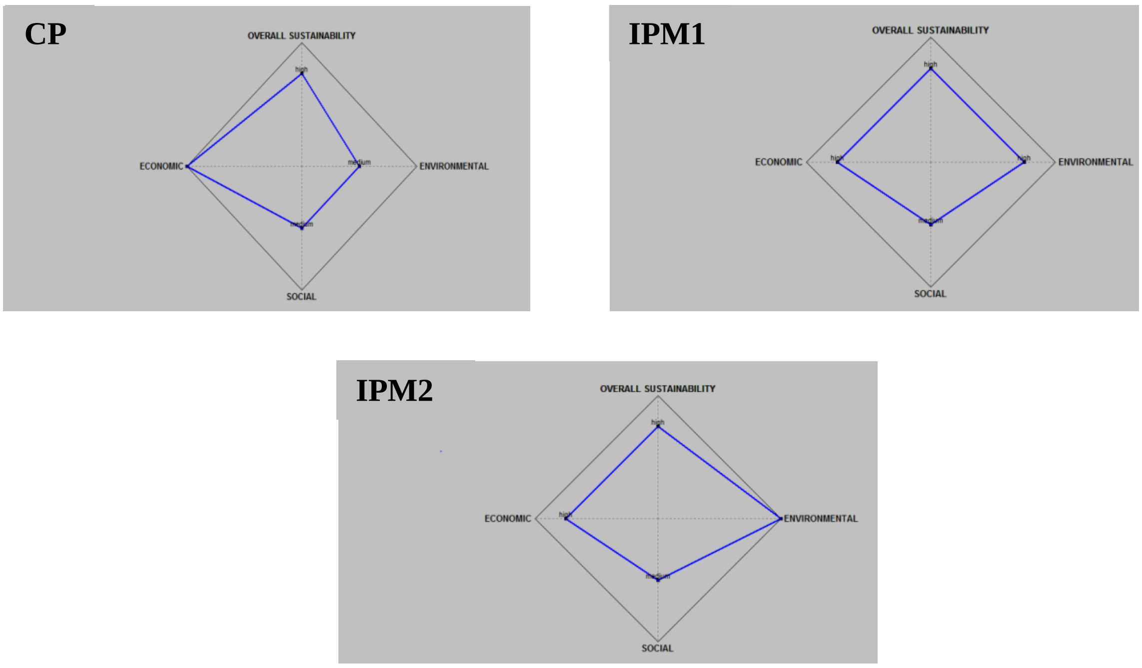

Figure 6. Schematic illustration of the outcome of the DEXiPM analyses of the INRA on-station experiment.

The results of the DEXiPM analyses of the four remaining on-station experiments will be available in the third period report.

The results of the SYNOPS analyses (1 m distance to water courses was assumed) are available for three of the six on-station experiments (Figure 7). Generally the ranking was CP>IPM1>IPM2. SYNOPS was not applied to the IPM2 system in the Arvalis trial as IPM2 was an organic scenario with no use of pesticides. The risk to terrestrial organisms and bees was very low in all cases except for the CP system in Denmark where it was low for terrestrial organisms only.

	Risk aquatic organism		Risk groundwater	
	Acute	Chronic	Single Substance	All substances
Germany	CP>IPM1>IPM2	CP>IPM1>IPM2	CP>IPM1>IPM2	CP>IPM1>IPM2
Denmark	CP>IPM1>IPM2	CP>IPM1>IPM2	CP>IPM1>IPM2	CP>IPM1>IPM2
France (Arvalis)	IPM1>CP	CP>IPM1	CP>IPM1	CP>IPM1
France (INRA)	CP>IPM1	CP>IPM1	CP=IPM1	CP=IPM1

Four risk categories
very low risk
low risk
medium risk
high risk

Figure 7. Outcome of SYNOPS for aquatic organisms and groundwater for the on-station experiments in Germany, Denmark and France (Arvalis).

The results of the cost-benefit analyses are available for all six on-station experiments. The results are summarized in Figure 8. With the exception of the experiment at INRA in France the gross margin was lower for IPM1 and IPM2 than for the CP system. The differences were most pronounced in the UK and at Arvalis in France. In the case of INRA trial, the low value of the CP system is explained by the very low yield of pea in 2014 (0.75t/ha, instead of a mean value of 3.5 t/ha measured regularly in this trial)

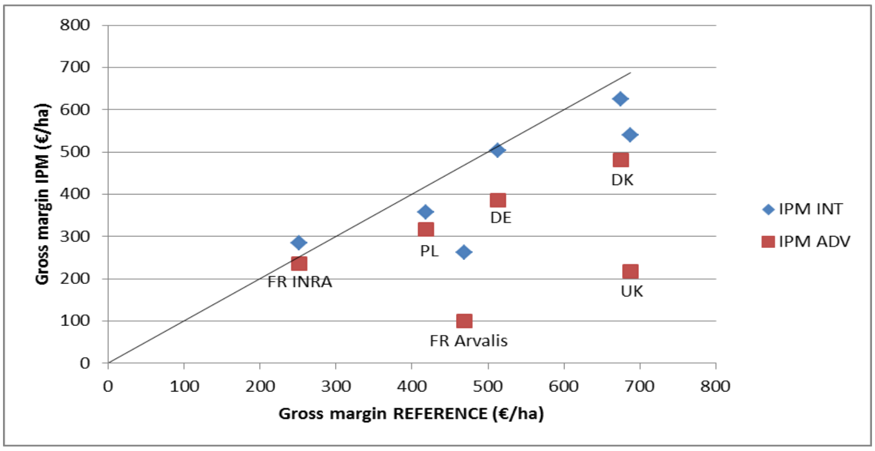

Figure 8. Summary of the cost benefit analyses.

5. Conclusion

5.1. Innovative methods

Various IPM tools were applied in the on-station and on-farm experiments. Some were successful while others were inconsistent in their performance. In the following the main lessons learnt from the experiments will be presented. Experiences from other crops than winter wheat will also be presented.

Crop diversity

Crop diversity in the rotation is considered a very efficient practice to minimise pest pressure and thus pesticide dependence. Four of the six on-station trials have only run for 3 years and no conclusions concerning the impact of crop diversity can be drawn. The two French trials have run for longer and have high diversity of crops but it is difficult to assess the effect of crop diversity because it is confounded by the effects of the other cultural differences between the CP, IPM1 and IPM2 systems.

Variety mixtures

Variety mixtures of winter wheat were used in several of the on-station experiments and were also the focus of some of the on-farm experiments. For example in the UK on-station experiment winter wheat in IPM1 and IPM2 consisted of 5 and 8 varieties, respectively. In the Polish on-station experiment a mixture consisting of two varieties was used in both IPM1 and IPM2 while in the Danish and French (INRA) on-station experiment IPM2 made use of a winter wheat variety mixture consisting of 4 and 3 varieties. The potential benefits of variety mixtures are illustrated very clearly looking at the assessments of septoria in the Danish experiment (Table 2). In all three growing seasons the level of attack in the control plots was lower in IPM2 than in CP (most widely grown variety) and IPM1 (a partly resistant variety) allowing a for reduced input of fungicides. The average TFI for fungicides in winter wheat for the CP, IPM1 and IPM2 systems were 1.35, 1,09 and 0.32, respectively.

Table. 2 Per cent of septoria attack on the flag leaf of winter wheat assessed at GS 75. The number of treatments in treated plots varied from 0 to 2.

		% attack of septoria on flag leaves			
		2012	**2013**	**2014**	**Average**
CP	Control	10.0	30.0	53.0	31.0
CP	Treated	0.7	3.0	21.0	8.2
IPM1	Control	0.1	32.0	21.0	17.7
IPM1	Treated	0	3.0	2.2	2.6
IPM2	Control	0.5	0.7	13.0	4.7
IPM2	Treated	0.5[1]	0	7.3	3.9

[1]No treatment with fungicides

Previous research by the UK partner mainly carried out in winter barley has shown that besides a better disease resistance variety mixtures also increases yields, contribute to stability and an increased resource use efficiency (see e-learning material on variety mixtures for more information. Thus variety mixture is not only an option for diseases like septoria where no fully resistant winter wheat varieties are available but also for diseases where this is the case.

In practice it can be difficult for farmers to purchase variety mixtures of good quality. In the Danish on-farm experiments examining variety mixtures several of the experiments had to be abandoned due to low quality of the seed material.

Considering the benefits of variety mixtures efforts should be made to convince seed companies and retailers to devote more attention to this IPM tool.

Weed harrowing

Weed harrowing was done in the IPM2 system in the two French, the Danish and the German (only the first two years) on-station experiments. The results revealed once again very variable effects of weed harrowing. In the German experiment weed harrowing in winter wheat resulted in unsatisfactory control in the second year of experimentation and resulted in a significant yield loss (Figure 3) and weed harrowing was replaced by low herbicide doses in the third year. Also in the French experiments were the effects of weed harrowing unsatisfactory but as no pesticides were used in the IPM2 systems mechanical weed control was the only option. Weed harrowing requires dry conditions which was not the case in 2014 at INRA.

In contrast in the Danish experiment satisfactory effects were obtained in spring oat. Result and experiences are generally better in spring cereals than in winter cereals and especially spring oat is very suppressive against the proportion of weeds that normally will survive weed harrowing. In the Danish experiment weed harrowing was only used once (spring 2013) in winter wheat in IPM2 where the condition for selective conduction was particular good. Especially, weed species with taproots and an erect growth habit are problematic to control by weed harrowing in winter cereals.

Inter-row cultivation

Inter-row cultivation was practiced in winter oilseed rape on several locations. Instead of sowing the crop at the standard 12 cm row distance it was sown at 50 cm row distance. This permits inter-row cultivation. In the two French experiments inter-row cultivation was also used in many of the rotational crops which traditionally are sown on a wide row distance. In the French (INRA) trial inter-row cultivation was also carried out in winter wheat sown at a row distance of 22 cm.

Winter oilseed rape is a very competitive crop and even though weeds in the rows will survive and may produce seeds no yield penalties were observed compared to the CPO system with broadcast herbicide applications. In recent years significant technical progress has been made with inter-row cultivators, e.g. fitting them with sensor systems permitting the inter-row cultivator to work closer to the crop and at a higher speed.

In less competitive crops like sugar beet and field vegetables, weeds in the row are more problematic than in winter oilseed rape. Advanced non chemical weeding tools that can remove weeds in the rows are therefore in high demand and fortunately commercialisation of such tools has just begun.

Inter-row cultivation can also be done in combination with band spraying but unfortunately little progress has been made in improving commercially available band spraying equipment and often this is the argument for not investing in advanced inter-row cultivators. Producers of band spraying technology should be encouraged to be more innovative.

Pesticide use

The study also showed that omitting the use of pesticides can result in pronounced yield losses in winter wheat but it also revealed that there is considerable scope for reducing pesticide use by adopting IPM measures without significant yield penalties. This is also highlighted by the fact that the yield losses in IPM1 (Figure 3) were small compared to the very significant reductions in pesticide use (Figure 4). With a few exceptions such as inter-row cultivation in winter oilseed rape and the use of variety mixtures in regions with low disease pressure combining IPM tools with a reduced input of pesticides seems for the moment to be the way forward implementing IPM. With the new innovative equipment for non-chemical weed control it may become feasible to skip herbicide use in row crops and new resistant genes and elicitors may offer an alternative to fungicides in the future.

Costs

Although many of the results were very promising considering the performance of alternative control methods it should be stressed that IPM as it was done in the on-station experiments was associated with a reduced gross margin. This can be attributed to the fact 1) that yields in Northern Europe are generally high and even a yield reduction of a few per cent is costly and cannot be compensated by the savings on pesticides, 2) that very few crops generate the same gross margin as winter wheat, i.e. most changes to the crop rotation will result in a reduction in the gross margin and finally 3) that many but not all of the alternative IPM tools are more expensive than pesticides. Hence the IPM1 and IPM2 systems should be further optimised to reduce the economic losses or alternatively farmers should be awarded for the benefits associated with IPM such as a reduced environmental impact.

5.2. Limitations

A major reason why chemical pest control has been successful, besides pesticides being relatively cheap compared to other inputs, is the reliability of pesticides. Even under adverse conditions high efficacy is normally achieved and failures are very rare. With the exception of maybe disease resistance (until it is overcomed by the fungi) most alternative control methods cannot provide the same high efficacy and certainly not the same reliability.

Mechanical weed control serves in this context as a good example. Inter-row cultivation is a very effective method between the rows but without band spraying or more sophisticated mechanical tools weeds in the row will be left undisturbed. Even though the surviving weed may not cause yield penalties they will produce seeds and contribute to the soil seed bank. Workable soils at the time of treatment and dry weather conditions in the following days are a pre-requisite for all mechanical weed control methods to provide high effects and in an experiment one can always find days with dry soil conditions. In practice where farmers have to treat many hectares this can be a challenge and lack of reliability is a major concern among farmers considering to invest in inter-row cultivators. Increasing the capacity of the inter-row cultivators and other tools for mechanical weed control is therefore crucial for their adoption among farmers.

Developing IPM therefore requires a very close collaboration between researchers, advisors, farmers and not at least the companies that will have to provide some of the tools required for successful adoption of IPM.