ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 102, No. 3 (2015), p. 325–334
DOI 10.13080/z-a.2015.102.042

Integrated crop and pest management of winter oilseed rape (*Brassica napus* L.)

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Abstract

The six major pests of winter rape in Europe: cabbage stem flea beetle (*Psylliodes chrysocephala*), cabbage stem weevil (*Ceutorhynchus pallidactylus*), rape stem weevil (*C. napi*), pollen beetle (*Meligethes* spp.), cabbage seed weevil (*C. obstrictus*) and brassica pod midge (*Dasineura brassicae*) are partly, sometimes fully, controlled by natural enemies. Crop management can either support or counteract this natural control. An objective of this European Union project No. QLK5-CT-2001-01447 was to design and test an Integrated Crop Management (ICM) system that aimed to be energy-efficient and high-yielding, giving a good economic net return yet with high natural control of pests and to compare it with a standard STaNdard (STN) farming system aimed to depict a modern way of growing rape. The two systems were compared in joint experiments in five countries. Non-inversion tillage was used to increase parasitisation of pollen beetle and seed weevil and activity-densities of ground beetles. Schedule spraying gave more control of stem weevil larvae than spraying to control thresholds. Differences in yield between the two systems were generally small. Where control thresholds were used, pesticide use was more than halved. Cost of soil tillage and the seed yield achieved were the main factors determining net return. Embedded energy of nitrogen fertiliser was more important than energy used for soil tillage. In the ICM system, total production costs, total energy use, labour and fuel costs were lower despite the need for one additional herbicide treatment; however, energy efficiency and nitrogen utilisation was a little lower indicating a need to better adjust nitrogen supply to yield level. A farming system based on the principles of ICM with non-inversion cultivation of soil can be recommended to farmers as a strategy to improve natural control of economically-important pests of winter oilseed rape, usually increase net return, decrease environmental impact and use less resources.

Key words: energy efficiency, insecticides, integrated crop management, integrated pest management, natural control, non-inversion tillage.

Introduction

In Europe, oilseed rape (*Brassica napus* L.) is grown from east to west in the northern regions, in both maritime and continental climates. Four insect species are common pests throughout the rape growing area: cabbage stem weevil (*Ceutorhynchus pallidactylus*), pollen beetle (*Meligethes* spp., mainly *M. aeneus*) cabbage seed weevil (*C. obstrictus* syn. *C. assimilis*) and brassica pod midge (*Dasineura brassicae*). The rape stem weevil (*C. napi*) is a serious pest only in Central Europe and the cabbage stem flea beetle (*Psylliodes chrysocephala*) is confined mainly to maritime areas (Alford et al., 2003). Each pest species has its own specific key parasitoids but these are the same throughout Europe (Ulber et al., 2010) and also similarities in the species composition of polyphagous soil-surface dwelling predators (Büchs, Alford, 2003). There is thus common ground for attempting to develop a European Integrated pest management strategy for protecting oilseed rape crops against economic damage from these pests. The routine use of pesticides is common practice throughout Europe: in the autumn once or twice against cabbage stem flea beetle, early in spring against rape stem weevil, later at least once against pollen beetle and cabbage stem weevil and finally during flowering or early pod setting against seed weevil and pod midge (Williams, 2010, Johnen et al., 2010). Resistance to insecticides in several of the pests has developed in recent years (Heimbach, Müller, 2013). Farmers would like to restrict insecticide use if this did not lead to yield loss. As production costs, particularly for energy and fertilizers, have increased in price, they would also like to cut these costs but without losing net profit.

An objective of the European Union project No. QLK5-CT-2001-01447 was to design and test an Integrated Crop Management (ICM) system for growing winter rape that aimed to be energy-efficient, high-yielding and more sustainable, giving a good economic net return with decreased use of pesticides and improved natural control of pests provided by parasitoids and predators.

Material and methods

Two production systems (STN and ICM) were compared in joint field experiments in five European Union countries: Estonia, Germany, Poland, Sweden and the United Kingdom, conducted over three years. Data for 2003–2004 and 2004–2005 were used in this analysis with one experiment in each of the countries each year (mostly data from 8 in total).

The STaNdard (STN) system is a modern way of growing winter rape in Europe, as in France or Germany (Cetiom or UFOP websites: www.cetiom.fr; www.ufop.de). The Integrated Crop Management (ICM) system was designed to enhance natural control of pests by greater parasitoid survival (Nilsson, 2010), to be more sustainable and resource-efficient than the STN system, with lower inputs of nitrogen (N) and diesel. The main differences between the two systems were in soil tillage and insecticide use. In the ICM system, non-inversion (reduced to 10 cm) tillage with no ploughing was used. Both systems had a 4 year rotation (to control soil diseases). Insecticides were either not applied (i0), applied prophylactically to schedule (ii) or according to local economic pest thresholds (ie) (Alford et al., 2003; Williams, 2010). Plots were at least 1 ha in area, to make it possible to use standard arm machinery and to allow for the natural distribution of pests and their natural enemies within plots. Soil surface predators are very mobile and differences between small plots could soon be eliminated.

In each country there was one STN plot and one ICM plot; their physical arrangement was randomised to produce a randomised block design with country/year blocks analysed in a two-way ANOVA. Means were compared using the Student-Newman-Keuls test. Part of the data were also tested with standard regression analyses and stepwise multiple regression. Experiments included some agreed set protocols but type and dose of pesticides, machinery used in reduced tillage, sowing date and amount of nitrogen applied were decided locally (for machinery used see Table 1, for pesticide and fertiliser applications – Table 2).

Soils of experimental fields varied from sandy to medium heavy clay. Clay content of soils in Germany, Poland and United Kingdom ranged between 20–40%, in Estonia and Sweden – 10–20%. Silt content was 40–60% in Estonia, Germany and United Kingdom, 20–40% – in Sweden and <20% – in Poland. Only in Sweden the experimental fields had been under reduced tillage for a longer period, and thus yields of the ICM plots in the other countries cannot give a full picture of the economic potential of this system.

In the STN plots, ploughing was done with a mould board plough, followed by re-compaction; a seed bed was created either by harrowing or by the combination of a rotary harrow and a seed drill. In the ICM plots, the stubble was worked into the soil with a cultivator (disc, tine or ducksfoot) shortly after harvest of the preceding cereal crop and usually re-compacted and again after 5–15 days with a rotary harrow, a disc cultivator or a chisel plough. Seeding was done as in the STN plots and at the same time around 15 August in Sweden and 25 August in the other countries, except in one case when seeding was delayed until 5 September.

A hybrid cultivar ('Banjo SW') of oilseed rape was used in both ICM and STN systems; seed came from the same seed batch and was dressed with insecticide (carbosulfan and imidacloprid + betacyfluthrin) and fungicides. In the ICM system, the seed was admixed with 2% turnip rape (cv. 'Salut') to produce an internal trap crop; turnip rape develops more quickly in the spring than oilseed rape and is more attractive to the bud-stage pests thereby reducing damage to the main oilseed rape cultivar (Nilsson, 2003).

Row spacing was 0.12 m. In the ICM plots, the goal was to achieve a final plant density of around 50 plants m^{-2}. To achieve this, the seed rate sown was usually higher than this to compensate for winter losses and slug, bird and mouse damage. To achieve an intended plant density is a general problem in rape cultivation and those achieved in the different experiments varied considerably. Sometimes, when plant losses were low (e.g., in Sweden) a higher plant density than intended was achieved, but more frequently plant densities were lower than the intended 50 m^{-2}; the median was 32 plants m^{-2} measured after overwintering, normally during late flowering or pod formation. Growth stage (GS) of crops was recorded at each sampling according to the BBCH scale (Lancashire et al., 1991). Nitrogen fertiliser was applied both in autumn (up to 75 kg ha^{-1} N) and spring, with a total amount of 170–275 kg ha^{-1} N (Table 2).

Pesticide applications made are summarised in Table 2. Different kinds of pyrethroid insecticide were used. The only exception was one treatment with chlorpyriphos in combination with cypermethrin. Fungicides were applied (mostly carbendazim) in some experiments and once in the autumn as a triazole growth regulator. All experiments were treated with herbicides, mostly metazachlor + quinmerac and propaquizafob or related compounds, and the ICM fields also with grass herbicides against volunteers (clethodim, dimethachlor). Metaldehyde was used against slugs in Germany.

Insect and disease assessments. Insect and plant samples were taken at various crop growth stages. Larvae

Table 1. Machinery used in STaNdard (STN) and Integrated Crop Management (ICM) systems winter oilseed rape experiments in 2003–2004 and 2004–2005 in Germany, Poland, Sweden and United Kingdom

	Working width m	Tractor power kW	STN	ICM	STN	ICM	STN	ICM	STN	ICM
			2003–2004		2004–2005		2003–2004		2004–2005	
			Germany				Poland			
Trailed 2500 l sprayer	24.0	90	6/4	4/1	5	3/2	5/4	7/6	6/5	5/4
Trailed cultivator, roller and levelling discs	5.0	180			1/0	1				
Carried seeder	4.0	90					1		1	1
Fertilizer spreader 2500 l with computer	24.0	90	2	2	3	3	2	2	3	3
Cambridge roller	12.0	90	1	1	1	1		1		
Disc harrow	6.5	180			2	1			1	
Trailed reversible 7 furrow plough and packer	2.8	180	1	1	1		1		1	
Pneumatic drill on power harrow	4.0	130	1	1	1	1				
Power harrow	4.0	130	1	2	1	1				
Combine harvester 230 kW	7.5	0	1	1	1	1	1	1	1	1
Stocks fan jet mounted on all-terrain vehicle	24.0	ATV	1	1	1	1				
Universal combi drill 4200 l	4.0	130						1		
Multi cultivator	5.0	180								1
			Sweden				United Kingdom			
Top cleaner with big rotor	6.0	180								1
Trailed 2500 l sprayer	24.0	90	5/1	2	6/4	4	5/3	–/3	6/5	5/4
Trailed harrow	9.0	130	2	1	1	1				
Trailed cultivator, roller and levelling discs	5.0	180		2		2	2	–/2		1
Trailed seeder 3300 l	6.0	130	1	1	2/1	1				
Fertilizer spreader 2500 l with computer	24.0	90	3	3	3	3	2	–/2	3	3
Cambridge roller	12.0	90	1		1	1	0/1		2	
Trailed reversible 7 furrow plough and packer	2.8	180	1		1		1	–/1	1	1
Pneumatic drill on power harrow	4.0	130					1	–/1	1	
Combine harvester 230 kW	7.5	0	1	1	1	1	1	–/1	1	
Universal not combi seeder	4.0	130								1

Note. Values for subsystems where treatments differed are given as STNii/ie and ICMie/i0, where application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

Table 2. Pesticide and fertiliser applications in the STaNdard (STN) and Integrated Crop Management (ICM) systems winter oilseed rape experiments in Germany, Poland, Sweden and the United Kingdom in autumn and spring 2003–2004 and 2004–2005

	Germany		Poland		Sweden		United Kingdom	
	STN	ICM	STN	ICM	STN	ICM	STN	ICM
			2003–2004					
No. of fertiliser applications*	2	2	5	5	3	3	2	missing
kg ha^{-1} N, autumn/spring	0/98	0/98	40/100	40/100	60/160	60/160	0/182	
			No. of applications, ii/ie					
Slug pellets	1	1	0	0	0	0	0/2	0/2
Herbicide	3	3	2	4	2	3	3	0/3
Fungicide**	0	0	1	1	0	0	0/1	0
Insecticide	6/3	3/0	3/1	1/0	4/0	0	4/2	0/2
Insecticide (half doses)	5/3	3/0	4/0.5	0.5/0	4/0	0	1.75/1.67	0/0.93
			2004–2005					
No. of fertiliser applications*	3	3	5	5	3	3	3	3
kg ha^{-1} N, autumn/spring	35/203	35/203	18/150	18/150	60/160	60/160	50/201	50/201
			No. of appplications, ii/ie					
Slug pellets	0	0	0	0	0	0	0	0
Herbicide	3	4	3	3	2	3	3	3
Fungicide**	0	0	1	1/0	3/2	2/1	1	1
Insecticide	4/1	1/0	2/1	1/0	3/0	0	4/2	2/1
Insecticide (half doses)	4/1	0.5/0	1.5/1	0	3/0	0	4/2	2/1

Note. Data are given for autumn/spring amounts or applications; * – once in autumn, ** – including growth regulators and for each subsystem, STN ii/ie and ICMie/i0 when different: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

of stem-mining weevils and the parasitoid larvae within them were obtained by dissecting ten randomly chosen plants from five randomly selected places in each plot. Pollen beetle larvae and the parasitoid larvae within them were collected in water traps placed on the ground at the time when the larvae dropped from the plant canopy to the soil for pupation. Usually at least 100 larvae were dissected, but numbers varied with catch size from 20 to more than 300. All sample results were transformed to m^{-2} values using plant density or trap surface area to allow comparison between experiments. During pod formation (usually at GS 80–83), plant samples of five plants were taken at random from three to five places in each plot. Length, stem base diameter and number of lateral racemes of the plants were recorded. Pods damaged by seed weevil and pod midge were counted on the main and third lateral raceme. Pod midge and seed weevil larval densities were estimated by taking 200 pods at random and either dissecting them or collecting the larvae exiting for pupation. The number of blind peduncles, some of them due to pollen beetle damage, and the length of stems with tunnels of stem-mining larvae in the main stem, were also recorded, and expressed as cm m^{-2}. Larvae from these stems were dissected for parasitoid larvae. Host larval density of cabbage stem weevil, pollen beetle and pod weevil were tested with a single classification ANOVA with unequal sample sizes, and the parasitisation frequency with a paired comparison two-way ANOVA. Activity-densities of ground beetles were assessed using 4 or 5 pitfall traps per plot in each system each year (from GS 65–97) when pest larvae were dropping to the soil for pupation and therefore most vulnerable to predation by ground beetles (Warner et al., 2008). *Verticillium*, *Sclerotinia* and *Phoma* incidence was recorded on samples of five plants from five places per plot taken close to or just after harvest.

Calculation of system performance. Data were collected on yield, its quantity and quality (crude fat content, protein content and 1,000 kernel weight), nitrogen, and machinery used. Nitrogen utilization was calculated as the ratio of nitrogen in seed yield to the amount of total nitrogen applied. Yields were estimated by taking the mean yield of four 20 m^2 strips from each plot. System economics were calculated using a standard net return method. Prices in Sweden were mostly used for all experiments; differences between countries were considered to be small, after reduction for local taxes and without any European Union subsidies. Local prices were used for pesticides as they vary greatly throughout Europe.

Income from seed yield in relation to production costs varies considerably due to world market prices and time of year and thus monetary comparisons were restricted to production cost. Other system performance indices that can be compared are energy in yield compared to energy needed for production, nitrogen utilization and different plant protection parameters. Costs for seed (same for all experiments), nitrogen, other fertilizers (same for all experiments), pesticides and machinery were calculated. Labour costs were derived from machine use time, with 20% added for preparation time. No other labour costs were included.

Each item introduced into the net return calculation was given an energy value. Energy of seed, especially in oilseed rape, is disproportionately high due to its oil content – 28.3 MJ kg^{-1} dry matter (Rathke, Diepenbrock, 2006). The energy of the seed sown was set to the energy costs of production, handling and packing (2.5 MJ kg^{-1}) and the quantity of seed sown was subtracted from the yield obtained (Zentner et al., 2004). For fertilizers, transport to farm, package and handling were added to manufacturing energy costs: N 38.7 + 1.3, P 12 + 1.3 and K 7 + 1.3 MJ kg^{-1} (Tzilivakis et al., 2005).

Calculations on pesticides were based on active ingredient (number of a.i. used, amount per ha) and compared to the recommended doses in Europe, which are fairly standard. Swedish, German and French national registers and advisory services were used. Few data on pesticide energy density (energy needed to produce pesticides) are available, so we took the average of the data for each group of pesticides (herbicides, fungicides, insecticides) using the data given by Green (1987), which is at present common practice (Hülsberger et al., 2001; Tzilivakis et al., 2005); for each pyrethroid we used the value of 580 MJ kg^{-1} a.i. given by Green (1987). Transport, handling and package were estimated to 23 MJ kg^{-1} (Tzilivakis et al., 2005). Current data were requested from pesticide producers but without success.

The farm machinery used in the different experiments differed in size and cannot be directly compared. The corresponding machines taken from the advisory service machine calculation database in Sweden and applied on a 500 ha farm with 100 ha oilseed rape were used. Machinery data included time used per ha (working speed), preparation time, replacement year, replacement value, maintenance costs, housing costs and draught requirement. The total crop draught requirement varies for different machines, and we used a 90, 130 or 180 kW tractor, assuming that all three tractors are needed on a 500 ha farm. Fuel consumption was calculated using an advisory model from the Swedish University of Agricultural Sciences, Uppsala (Arvidsson et al., 2004) and based on Swedish field measurements. Fuel consumption in this model is a function of tractor weight (0.17 L ha^{-1} and kg) and the machine type, width and working depth, speed and clay content. The life span of farm machinery is important for the partitioning of manufacturing energy cost per ha, and different values can give different outcomes to the total energy budget. After consultation with the Advisory Service, we set the total lifespan of equipment to 2,500 h, a combine to 5,000 h and a tractor to 10,000 h. A 15% higher capacity utilization could probably have been possible on some farms, but the figures given here should represent a mean high capacity utilization of a large farm. Energy density (manufacture and transport to farm) of equipment based on their composition of iron, steel, plastic and other material has been calculated to be 76 MJ kg^{-1} for tractors and combine, 94 MJ kg^{-1} for sprayers and 111 MJ kg^{-1} for all other machinery (Sonesson, 1993). Diesel has an energy value of 39.6 MJ L^{-1} (Rathke, Diepenbrock, 2006). Labour energy can be set to 0.5 MJ h^{-1} using standard cost recommendations, which gives a negligible contribution to the total energy balance.

Drying of the seed and transport from the farm are determined by local conditions and prevailing weather and their costs were omitted. We added 6 € and 143 MJ ton^{-1} seed and 11 € ha^{-1} to account for analyses, insurance and other fixed costs. An interest rate of 5% was also added.

Results and discussion

Crop growth and yield. Spring growth usually started first in the United Kingdom and a few weeks later in the other countries, with Germany a little earlier than Sweden, Poland and Estonia. Development rates were similar in spring and early summer, almost linear for growth stages 40–90 against day number but could differ in the autumn due to differences in sowing date and time when temperatures were above zero.

Mean yield from the systems over years and sites was around 3.5 t ha^{-1}, close to the mid-European level during this period. The standard (STNie) system yielded about 300 kg (10%) more than the integrated (ICMie). The oil content of seed did not differ between systems (Table 3).

Table 3. Yield (kg ha^{-1} wc 9%) and yield quality in the four trials of 2004 and of 2005 (n = 8)

Comparison	System and treatment	Seed yield kg ha^{-1}	Relative yield	Crude oil %	Pods No. m^{-2} (n = 9)	1,000 kernel weight
A	STNii	3667	100	48.4	3028	4.4
B	STNie	3580	98	47.6	2957	4.3
C	ICMie	3312	90	47.6	2699	4.1
D	ICM i0	3105	85	47.4	2449	3.9
	Significant difference	AB ≠ CD		ns	ns	A ≠ D
	Probability	0.001		0.13	0.17	0.031
	Coefficient of variation	2.6		0.63	7.2	2.7

Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0). Pod counts are from top and 3rd raceme. ns – not significant at $P < 0.05$.

Yield-forming factors, e.g., nitrogen (N) fertilization, plant densities, pods and lateral racemes per m^{-2} stem base diameter and 1,000 kernel weight, were analysed using stepwise multiple regression against seed yield with dummy factors for site, year and system. Nitrogen fertilization, plants and pods m^{-2} explained 80% of the variation in yield. Yield was linearly dependent on nitrogen fertilization (140–240 kg ha^{-1} N, 15.6* nitrogen supply; R^2 = 0.47) and logarithmic on number of pods (with at least one seed; 810.3 ln (pods) – 2867; R^2 = 0.41). There was no statistically significant difference between systems in pod density, but a trend similar to difference in yield. 1,000 kernel weight was lower in the plots that received no insecticides, indicating that pest damage affected yield (Table 3).

Production costs and energy use. Reduced tillage and a lower use of insecticides through the use of control thresholds lowered production costs. It also reduced labour hours; this could mean that, on a large farm, fewer employees would be needed, in turn leading to a substantial increase in profitability (Table 4).

Table 4. Costs of various production inputs and energy use per ha for the different systems

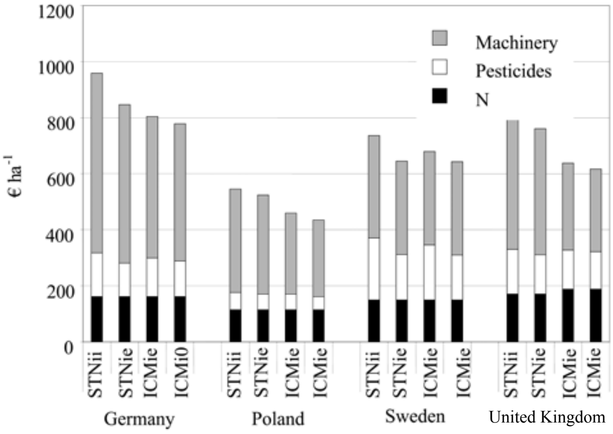
Comparison	System and treatment	Total costs € ha^{-1}	Labour h ha^{-1}	Total energy use MJ ha^{-1}	Fuel L ha^{-1}
A	STNii	834	4.7	13649	77
B	STNie	786	4.3	13353	77
C	ICMie	738	4.0	12849	65
D	ICMi0	733	3.9	12834	65
	Probability	0.000	0.001	0.002	0.02
	Significant difference	A ≠ BCD B ≠ CD	A ≠ CD	AB ≠ CD	A ≠ CD
	Coefficient of variation	1.7	3.1	1.1	3.6

Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

Variation in costs between experiments and between years was considerable. In Figure 1, results from four experiments (2004–2005) are shown. Costs of machinery were more important than costs of pesticides and nitrogen fertilizers. Costs of other inputs are not shown, as these were more or less constant between experiments and systems. There was substantial variation in machinery costs between experiments, to some extent dependent on soil clay content, but also on choice of machinery, especially for reduced tillage. Looking specifically at the Swedish and United Kingdom experiments (Figs 1 and 2), which had the best net returns, these experiments had a high yield and a lower use of machinery, the difference between the two being caused by a higher clay content in the United Kingdom soil.

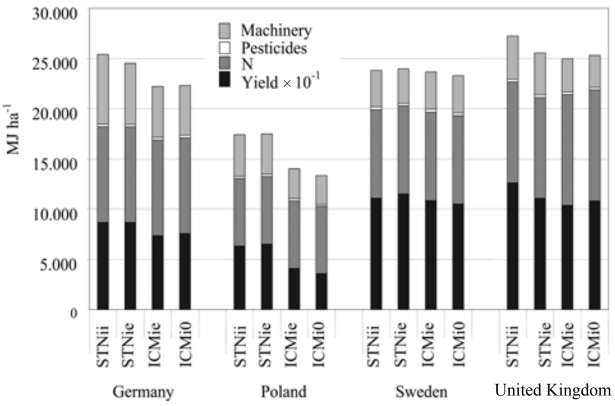
Comparison of the energy gain in yield and the energy cost of production (Fig. 2) gives a different picture. The nitrogen fertiliser now dominates and as prices of energy are predicted to increase in the future, N will be an increasingly important factor in plant production (Hülsberger et al., 2001). Moreover, less energy (5000 MJ ha^{-1}) was used in the Polish than in the United Kingdom experiment, but less energy (50000 MJ ha^{-1}) was also harvested in the seed yield, illustrating the importance of having an optimal and not a minimal level of inputs.

Use of external resources and environmental impact. Nitrogen use was high with N fertilizer input from 140 to 240 kg ha^{-1} N. Nitrogen was an important yield determining factor; it also determined seed protein



Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

Figure 1. Costs of main variable inputs in four experiments in 2004–2005



Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

Figure 2. Energy gain (×10^{-1}) and energy costs of main variable inputs in four experiments in 2004–2005

content and thus the value of the seed press residues used as protein fodder for livestock. The protein (and N) content of the seed varied with yield and ranged between 90–100 kg ha^{-1} N (Table 5).

However, much of the applied N is not removed with the seeds, but left in the soil as plant residues that could be lost in leaching of nitrate when mineralized during the following winter and spring (Sieling, Kage, 2006). The relationship between applied and harvested N (N utilization) was 40–50% and increased with increasing yield. For comparison, the corresponding value for winter wheat is 70% or more. Obtaining a high yield is thus important not only for the net return, but also to minimize environmental impact. Losses in crop yield can often be related to losses of photosynthetic ability due to weeds (shadowing) and to pests and diseases, which can greatly reduce N efficiency. A high N utilization rate is also important, as the energy content of N fertilisers is a very important component of the energy balance of the crop (Zentner et al., 2004).

The manufacturing and use of machinery is usually an important part of the energy needed to grow an oilseed rape crop. The sustainable farm would thus minimise soil tillage and also aim to simplify tillage operations so as to use fewer machines. The ICM system used less energy than the STN system, and one important saving was in fuel. Thus, the ICM system used less non-renewable resource and produced less pollution; this has also been shown in other studies (Bailey et al., 2003; Trewavas, 2004). However, the energy efficiency of the ICM system was a little lower, mainly due to lower yield (Table 5).

Plant protection, pests and diseases. The most severe pest damage was from stem-mining insects, mainly from the cabbage stem weevil. Stem damage was much lower in the schedule-sprayed plots (STNii) than in the others and much more in plots where no insecticides (ICMi0) were used. The cabbage stem flea beetle was rare during the period of the experiments. Although there were fewer pollen beetle larvae in the STNii than in other plots, there was no evidence of differences in buds lost (blind peduncles) (Table 6). The insecticides used during flowering probably lowered the larval population in this plot. Blind peduncles represented only about 10% of the number of pods, and should have been compensated for by the plants. Damage by seed weevil and pod midge was not important, with a few exceptions. In Poland in

Table 5. Nitrogen (N) recovery in harvested seed in 2004 and 2005 (n = 8)

Comparison	System and treatment	N yield kg ha^{-1} in seed	N utilization (n = 6)	Energy gain / energy cost
A	STNii	102	0.50	6.6
B	STNie	102	0.48	6.6
C	ICMie	95	0.42	6.3
D	ICMi0	88	0.41	6.0
	Significant difference	AB ≠ D	AB ≠ CD	AB ≠ D
	Probability	0.006	0.002	0.029
	Coefficient of variation	3.2	3.6	2.6

Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0); N utilization = N recovery/N fertilization (autumn + spring application).

2004, 15% and 25% of the pods in the two ICM plots were infected by weevil larvae, while substantial pod midge damage was recorded in Sweden in 2003 and in the United Kingdom in both 2004 and 2005, with as many as 40% damaged pods in the STNii plot in 2004, and with about 10–15% damaged pods in the other plots. As pods per m^2 is one of the yield determining factors of importance, it cannot be excluded that these losses of pods, due at least to pod midge, also lowered the yield.

Table 6. Stem damage and cabbage stem weevil density in 2004 and 2005 in Estonia, Germany, Poland, Sweden and the United Kingdom

Comparison	System and treatment	Stem damage cm m^{-2}	Cabbage stem weevil larvae No. m^{-2}	Blind peduncles No. m^{-2}	Pollen beetle larvae No. m^{-2}
A	STNii	220	30	345	254
B	STNie	680	113	380	618
C	ICMie	570	42	253	914
D	ICMi0	739	170	255	906
	Significant difference	A ≠ D	AC ≠ D	ns	A ≠ CD
	Probability	0.046	0.039	0.206	0.017
	Coefficient of variation	24.0	36.0	13.4	22.1

Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0). ns – not significant at $P < 0.05$.

Stem diameter is a measure of plant size and thus of the plants' potential to produce pods. In Figure 3, yield is plotted against stem diameter and plots with strong stem damage (>1000 cm m^{-2}) and with a high number of pod midge damaged pods m^{-2} (as defined above) are shown. The aberrant data for United Kingdom 2003 have no apparent explanation. Figure 3 indicates that pod loss reduces yield more than stem damage. Stem disease attack, due to *Verticillium*, *Sclerotinia* and to a minor extent also *Phoma* was probably another important yield-determining factor. In Germany and Sweden in particular, and in some years in Poland, almost all plants were affected in both systems alike, whereas almost no attack was recorded in Estonia. Oilseed rape is a relatively new crop and soil diseases have not yet accumulated (Dixelius et al., 2005).

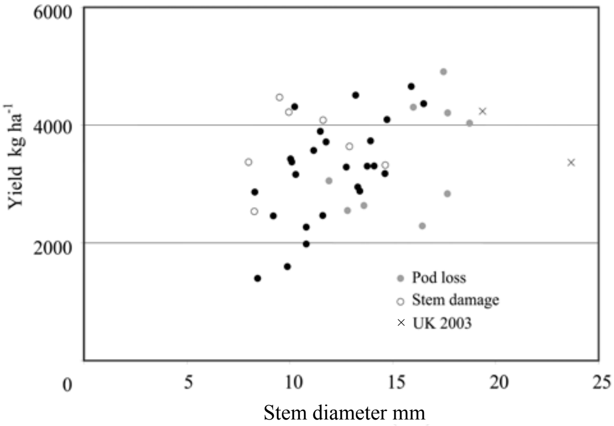


Figure 3. Yield as a function of stem diameter and pest damage

Pesticide inputs. The number of active ingredients of pesticides applied was greater in the schedule sprayed (STNii) system than in the other systems. In systems where thresholds for control of insects were used, the number of insecticide applications was more than halved. More herbicides were used in the ICM system with reduced tillage, because of the need to kill volunteer plants of the preceding cereal crop; these were ploughed under in the STN system (Table 7). When insecticides were applied to schedule (STNii), on average 3.5 applications were needed. This included any treatments against the cabbage stem flea beetle or other insects sometimes required in autumn to establish the new crop (also in ICMi0).

Application of insecticide at a dose lower than that recommended is one way of reducing pesticide input and the concept "ha-dose" is based on a comparison of the dose used that is recommended by the advisory services or mentioned in registration of the pesticide (Table 7). More variable doses could probably have been used as there is a "security" part in dose recommendations. Doses can usually be lowered at optimal use, without risking an increase in pest resistance. Schedule spraying (STNii) reduced the amount of stem damage considerably (Table 6), but did not eliminate pod midge damage. Prediction of the need to control stem-damaging insects could be improved by the use of decision support systems, e.g., ProPlant (Johnen et al., 2010), and the use of selective field traps, e.g., pheromone traps. It should be possible to achieve the same control of pests with the aid of control thresholds as with schedule spraying.

Table 7. Mean numbers of active ingredients (a.i.) of total pesticides, herbicides used and applications and dose rates of insecticides applied to different management systems

Applications	STNii	STNie	ICMie	ICMi0
Pesticide a.i.	7.1	4.6	4.6	4.1
Herbicide a.i	2.6	2.6	3.3	3.3
Insecticides applications	3.6	1.3	1.0	0.4
Insecticide doses	3.4	1.1	0.9	0.2

Notes. Insecticide doses – the sum of the quota between the dose actually used and the dose recommended by advisory services or mentioned in registration of the pesticide. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0).

The need of fungicides and the tradition of their use were very different between countries (Table 2). In Germany and Sweden, fungicides were not used. In Sweden, where *Phoma* is of less importance, metconazole was sprayed in September and in the spring for growth regulation. In Poland, sprays were applied at the end of flowering against pod and stem spot diseases and, in the United Kingdom in late autumn against light leaf spot. With few exceptions all treatments were sprayed and their impact cannot be estimated.

Activity-densities of predators. Ground beetles, rove beetles and spiders are the main predators in oilseed rape crops (Büchs, 2003). Pitfall traps caught a total of 32 and 23 species of ground beetle that were dominant (>1% of the catch) in the ICM and STN systems, respectively, with *Amara similata* one of the most important. Most species were active in June, the time when larvae of most pest species drop to the soil to pupate (Felsmann, Büchs, 2006; Warner et al., 2008). Although numbers caught were very variable between plots in the same year, between years and between crops, in five of the six experiments (2003–2005) they were greater in the ICM than in the STN system. This trend concurs with results of other studies both on oilseed rape (Büchs, 2003) and cereals (Holland, Luff, 2000; Hance, 2002) showing that species richness and activity-densities increase with more extensive management systems, reduced tillage and lower pesticide inputs. However, the drawbacks of pitfall trapping as activity-density traps (Adis, 1979) make the effects of husbandry on ground beetle abundance difficult to interpret. Staphylinids and spiders were assessed only in Germany in 2003 and 2004 (Felsmann, Büchs, 2006). Spiders, known to be very sensitive to pyrethroids, were significantly more abundant in the ICM than in the STN system in both years.

Parasitism of pest larvae. Parasitism of pest larvae is a function of host density and time of pesticide application and migration of parasitoids and hosts. Only in the United Kingdom and one year in Sweden was the crop treated with insecticides during full flowering in the STN plots. In all other instances, treatments were made during bud stage or with only a few open flowers in the crop. Insecticides were rarely used in the ICM part. When they are used according to thresholds against pollen beetles this will also coincide with the migration of cabbage stem weevils and lower the number of stem mining larvae. Pollen beetles migrate to the crop during a longer period and their larval density is less dependent on pesticide use in the bud stage. Pod weevil will not be affected very much as it arrives later (Table 9). Plots sprayed to thresholds, especially in the ICM system, had more pest larvae which is important for the maintenance of the parasitoid populations (Table 9).

Relative parasitisation (% of host larvae parasitized) is also influenced by host density as the density of parasitoids is usually adjusted to host density through migration; it is not expected to be very different at different host densities. Pollen beetle larvae are attacked by several species of parasitoid (Ulber et al., 2010). The densities of pollen beetle larvae differed greatly in different plots. There is a constant relationship between pollen beetle larval density and parasitized pollen beetle larval density (Table 8).

Table 8. Relationship between densities of pollen beetle larvae and parasitized pollen beetle larvae in different countries

	Years	No. of trials	Regression coefficient	R^2	Host density range No. m^{-2}
Estonia and Poland	2003–2005	14	0.29	0.83	140–1.690
Germany	2003–2005	8	0.35	0.85	4–430
Sweden	2003, 2005	5	0.70	0.98	370–1.700
United Kingdom	2004, 2005	6	0.49	0.84	10–2.380

Linear regression (through zero) for these relationships explains more than 80% of the variation. Each regression describes data for years and plots of a country. This indicates that the number of parasitoids per host larva is determined by more general factors than those restricted to the studied crop. This is also indicated by a comparison of the relative parasitisation in pesticide treated and untreated plots for the three species compared. The variation is too high for any difference to be proven for a single species, but 22 out of 27 comparisons show that the parasitisation is higher in untreated plots. Taken together for all comparisons this is highly significant and indicates that pesticides have a negative effect also on relative parasitisation levels (Table 9).

Table 9. Host larval density

System and treatment	Host larval density m^{-2}			% parasitisation			
	cabbage stem weevil	pollen beetle	pod weevil	cabbage stem weevil	pollen beetle	pod weevil	all
STNii	4.2	123.4	35.4	13.5	31.1	18.6	23.7
STNie	29.6	151.9	42.9				
ICMie	12.2	276.4	55.0				
ICMi0	80.8	644.8	61.1	14.1	38.2	31.0	31.3
Probability	<0.001	ns	ns	ns	ns	ns	<0.001
n	40	36	43	10	26	18	54

Notes. STN – StaNdard system, ICM – Integrated Crop Management system. In each system different insect control strategies were used: application of insecticides was prophylactic (ii), according to economic pest thresholds (ie) and not applied (i0). Mean values after transformation and re-transformation with 10 log (x + 1). Relative parasitisation (% of hosts with parasitoid larvae, number of dissected hosts >15); ns – not significant at $P < 0.05$.

A potential way of increasing the population density of some parasitoids is to minimize their mortality during hibernation. The univoltine parasitoid species (mainly *Tersilochus* species) of our key pests hatch in early autumn in the soil of the rape field and hibernate in the pupal cell. Soil cultivation of the rape stubble to establish a new crop, often winter wheat, kills a large proportion of overwintering parasitoids. Reduced tillage, and in particular direct drilling (Nilsson, 2010), can greatly increase the number of parasitoids emerging the following spring. If reduced tillage had been practised on all farmland surrounding the ICM experiments it is likely that the populations of univoltine parasitoids of many pest species would have been higher and the differences between parasitisation levels thus also greater.

Conclusion

These experiments demonstrated that a farming system based on integrated crop management (ICM) principles, with non-inversion soil tillage and use of pest control thresholds to determine the need for insecticide application, can be recommended to farmers as a strategy to enhance natural enemy populations; it would improve natural control of economically-important pests of oilseed rape, and, at the same time, often get a better net return, use less resources and decrease environmental impact.

Acknowledgements

The project MASTER (QLK5-CT-2001-01447) was part-funded by the EU under its Framework 5 Quality of Life and Management of Living Resources programme. We thank the many scientists, students, farm workers and statisticians who helped with this project.

Received 17 12 2014
Accepted 20 07 2015

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ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 102, No. 3 (2015), p. 325–334
DOI 10.13080/z-a.2015.102.042

Žieminio rapso (*Brassica napus* L.) pasėlių ir kenkėjų integruotas valdymas

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Santrauka

Šeši pagrindiniai Europos rapsų pasėlių kenkėjai: rapsinė sprageė (*Psylliodes chrysocephala*), kopūstinis stiebinis paslėptastraublis (*Ceutorhynchus pallidactylus*), rapsinis stiebinis paslėptastraublis (*C. napi*), rapsinis žiedinukas (*Meligethes* spp.), ankštinis paslėptastraublis (*C. obstrictus*) ir ankštarinis gumbauodis (*Dasineura brassicae*), yra iš dalies arba ir visiškai kontroliuojami jų natūralių priešų. Pasėlių priežiūra šią natūralią kontrolę gali arba stimuliuoti, arba slopinti. Europos Sąjungos projekto Nr. QLK5-CT-2001-01447 tikslas – sukurti ir išbandyti integruotą pasėlių valdymo sistemą, kuri efektyviai vartotų energiją, užtikrintų didelį derlių, būtų efektyvi ekonominiu atžvilgiu ir užtikrintų efektyvią natūralią kenkėjų kontrolę, ir ją palyginti su standartine ūkininkavimo sistema. Šios dvi sistemos buvo palygintos vykdant bendrus eksperimentus penkiose šalyse. Siekiant padidinti rapsinių žiedinukų bei ankštarinių paslėptastraublių parazitavimą ir žygių veiklos tankumą, taikytas neariminis žemės dirbimas. Purškimas pagal nustatytą grafiką buvo efektyvesnis kontroliuojant stiebinių paslėptastraublių lervas nei purškimas priklausomai nuo žalingumo ribos. Derliaus skirtumai tarp šių dviejų sistemų nebuvo dideli. Ten, kur buvo purkšta atsižvelgiant į žalingumo ribą, pesticidų sunaudojimas sumažėjo daugiau nei per pusę. Žemės dirbimo kaštai ir sėklų derlius buvo pagrindiniai veiksniai, lemiantys grynąjį pelną. Energija, suvartota įterpiant azoto trąšas, buvo svarbesnė nei energija, suvartota dirbant žemę. Integruotoje pasėlių valdymo sistemoje bendri gamybos kaštai, bendras suvartotos energijos kiekis, darbo ir kuro kaštai buvo mažesni, nepaisant dar vieno papildomo purškimo herbicidais. Tačiau energijos efektyvumas ir azoto įsisavinimas buvo šiek tiek mažesni; tai rodo, kad tręšimą azotu reikia taikyti atsižvelgiant į derliaus lygį. Ūkininkavimo sistema, kai integruotas pasėlių valdymas yra derinamas su neariminiu žemės dirbimu, gali būti rekomenduojama ūkininkams kaip strategija, skirta pagerinti ekonomiškai svarbių žieminių rapsų kenkėjų natūralią kontrolę, padidinti grynąjį pelną ir sumažinti poveikį aplinkai bei naudoti mažiau resursų.

Reikšminiai žodžiai: energijos efektyvumas, insekticidai, integruotas kenkėjų valdymas, integruotas pasėlių valdymas, natūrali kontrolė, neariminis žemės dirbimas.