Integrated crop protection as a system approach

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Abstract: New farming systems in vegetable production are required as demands for high quality products that do not pollute the environment are rising, and production risks are large and incomes low. The methodology of prototyping new systems is described, especially the themes, parameters and target values connected to integrated crop protection. The role of integrated crop protection in prototyping new systems is discussed. The results of twenty years working with this prototyping methodology are presented with a focus on results related to crop protection. As well, results of experimental farms as results of commercial farms are presented. The results indicate that by application of the methodology, large steps forward can be made in making farming systems more sustainable and ambitious environmental targets can be reached. The total system approach is an indispensable step in the development of an individual crop protection technique to implementation of this technique in practice. Therefore, more cooperation is needed between specialists on certain crop protection aspects and the generalist system researchers. In this way the developement of more sustainable crop protection in special and more sustainable farming systems in general can be really succesful.

Key words: pests, diseases, integrated control, prototyping, systems, indicators, the Netherlands

Introduction

Although vegetables cannot be said to be a key issue in agricultural policy in the Netherlands, they are, nevertheless, major constituents of the daily diet of many people. Consequently, it is very important to ensure the availability of a wide variety of relatively inexpensive, high quality, fresh vegetables on a daily basis.

The farms throughout Europe producing field-grown vegetables are characterised by very intensive use of land with short crop rotations, concentrated in certain regions. One consequence of this is that crops are under the constant risk of being decimated by pests and disease. Labour and capital requirements are high and costs of inputs as pesticides are low. Besides, (cosmetic) quality requirements are high. This situation causes the intensive, but increasingly ineffective, use of pesticides (and nutrients).

Consumers and market parties as retailers are worried about pesticide residues and high nitrate contents in vegetables. Besides, government authorities are worried about the environmental quality in vegetable growing areas. There is a growing public demand for production methods that have an “ecological content”. The problem is that consumers and market parties are also demanding high quality products for low prices at the same time.

There is an urgent need for new farming systems focusing not only on yield but on product quality and the quality of the a-biotic environment as well. Therefore, the old one-sided (mainly agrochemical-based) methods have to be reconsidered, redesigned, and replaced by new multi-objective methods that are able to meet all new objectives.

Integrated farming is one of the two major visions with respect to integral approaches towards agriculture (next to organic farming). System researchers are exploring the potential contribution of integrated farming to the future of agriculture.

Crop protection is next to crop rotation and nutrient management, an important method of integrated farming. To get working solutions for farmers, these methods have to be seen in the context of the total farm to get a sustainable system. Looking at single methods or even parts of methods is often not sufficient.
In the last fifteen to twenty years, integrated crop protection has always been a central point in the design of integrated arable and vegetable farming systems. This article gives an overview of the research methodology of prototyping focussed on integrated crop protection. Besides, an overview of the most important results is presented to illustrate the strength and impact of the methodology.

Material and methods

Methodology farming system research

For the development of sustainable vegetable-farming systems, a standardised methodology called "prototyping" is developed. The methodology is a combined research and development effort beginning with a profile of agronomic, environmental and economic demands (objectives) for more sustainable, future-oriented farming and ending with tested, ready-to-use prototypes, designed for widespread use. It consists of four phases: 1) analysis and diagnosis, 2) design, 3) testing and improving and 4) dissemination.
The prototyping methodology was examined for arable farming in a four-year European Union Concerted Action (Vereijken, 1994; Vereijken, 1995 and Vereijken, 1999) and further developed for vegetable farming during the EU-VEGINECO-project (Sukkel and Garcia Diaz, 2002).
The first phase in prototyping starts with a regionally based analysis of the prevailing agricultural systems resulting in a diagnosis of the situation in terms of sectorial statistics, farm structure, agro-ecological state-of-the-art, ecological–environmental impact, the socio-economic situation and trends in structural changes and political conditions.
The design phase starts by establishing objectives for all-round sustainable farming systems (Vereijken, 1994). In the VEGINECO prototyping practice, these rather abstract objectives are translated into five directional themes: "quality production", "clean environment", "attractive landscape and diversified nature", "sustainable management of resources", and "farm continuity". For each theme, a limited number of relevant parameters are defined on farm-level to characterize the main elements of the systems performance. Each parameter is given a target value. The targets are future oriented and are derived from legislation, scientific evidence or expert knowledge. The themes together with the parameters and target values represent an ambitious reference for the farming systems that are being designed, tested and improved.
The next step is to design a suitable set of farming methods. Methods are defined here as coherent strategies on the major aspects of farming. Methods are for example "multifunctional crop rotation", "integrated nutrient management" and "integrated crop protection". In most cases, these methods need further development if they have to reach the objectives set.
The next step in the design comprises the design of a "theoretical prototype" combining all methods. When the theoretical prototype is finished, it needs to be checked if the theoretical prototype is able to meet the targets set for the parameters. This is often an expert judgement. The last part of the theoretical exercise ends with detailed cropping programmes, allowing for adjustments that might be necessary for specific crops, weather and soil conditions.
The third phase is testing and improving the farming system that has been designed in practice for a couple of years. This is often a time-consuming and laborious process. Every year the actual value of the parameters has to be determined and compared to the target

values. Shortfall to the target values has to be analysed. Agronomic information and observations during the growing season are then indispensable. The method(s) causing the shortfall have to be identified and improved.
Testing can be done on experimental farms or commercial farms. Experimental farms are preferred when the distance between actual and target values are large and experimental freedom is required. Testing on commercial farms is preferred when more locations are needed or when information on manageability and acceptability by the farmers of the prototype is important (de Haan & Garcia Diaz 2002).
When testing and improving results in a stable system, fulfilling (almost) all objectives, the results can be spread out to other farmers, advisory services and other stakeholders in the production process. The exact prototype is not disseminated, but merely the underlying integral approaches to farming, the farm methods and the toolbox with a practical guide to adjust the strategies to the local conditions. Besides, communication about the project is important with all stakeholders from the start of the project.

Themes and parameters to quantify the effects of the integrated crop protection method
Integrated crop protection is one of the major farming methods distinguished in prototyping. Integrated crop protection has a strong relationship with the themes “quality production” and “clean environment”. The theme “quality production” is influenced by the prevention of yield and quality reduction by harmful species, pesticide damage to the crop and pesticide residues on the crop.
The theme “clean environment” is strongly influenced by the use of pesticides. The use of pesticides results in the emission to different environmental compartments (air, surface water, soil and groundwater) and in damage that can be done to non-target species (Figure 1). Pesticides can damage biota in general and the ecosystems in water and soil in particular. The use of pesticides is currently often quantified as the number of treatments or as kilograms of active ingredients. These parameters only quantify use and production technique and are often used in target levels for policy purposes
However, pesticide input gives no information on how and to what extent pesticides are dispersed in the environment and on the extend of damage to non-target biota. To quantify the emission to the (a-biotic) environment independently, a concept called Environment Exposure to Pesticides (EEP) was developed. The EEP quantifies emission risks; the use of it in prototyping reflects the “precautionary principle”: what is not there cannot do any harm. EEP is quantified for emission to air, soil and groundwater by taking into account the active ingredient’s physical properties (DT50, soil half-life; VP, Vapour pressure; and Kom, bonding to organic matter) and the amount used (Wijnands 1997, Sukkel & Garcia Diaz 2002, see appendix).
This tool is instrumental to the aim to minimise any potential effect of pesticides on flora and fauna. Therefore, the exposure of the environment to pesticides (EEP) should be minimised. This should be accomplished by minimising the pesticide requirements of farming systems (integrated crop protection) and consequently by the careful selection of pesticides, taking into account the extent to which the environment is exposed to pesticides. The quantification of pesticide us in terms of emissions enables a ranking of pesticides on farm level, showing the extend of the contribution of a single compound to the total emission
Based on this, yearly solutions can be sought for the highest scoring pesticides, either by preventing the use of these pesticides changing the integrated crop protection strategy or by replacing them with less scoring pesticides.

Most other approaches to assessing pesticide risks focus on the effect on biota. For instance, the environmental yardstick (EYP), as developed by CLM in the Netherlands, is one of these approaches (Reus & Leendertse, 1999). The EYP calculates ecological risks for fauna in surface water and soil.
An overall comprehensive assessment of ecological risks is virtually impossible. Overall quantitative scores of “ecosafety”, therefore, may easily lead to unjustified classification of a pesticide as being safe. It is not said that additional ecological information is not useful. However, selection of pesticides only based on ecological effects may be misleading. Therefore, the EEP approach is leading in prototyping and the EYP values are only used on the second place.
Target values are derived from various sources. For EEP-air the target was derived from the Dutch crop protection policy, for EEP-groundwater, the EU-legislation on drinking water and groundwater quality is followed (0.5 ppb) and the target value for EEP-soil was derived from technical results on experimental farms. For the EYP-parameters no treatments can have more than 10 (water life) or 100 points (soil life). This reflects more or less the no direct toxicological effect level (with a safety factor of 100). The target value for active ingredient use is crop specific depending on technical possibilities.

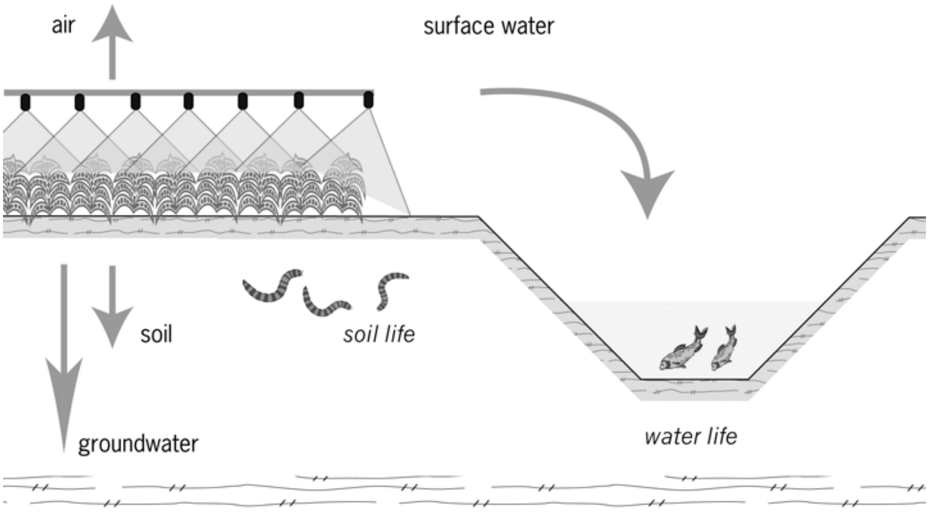

Figure 1. The main emission routes and ecological effects of pesticide use

Integrated crop protection method
Integrated crop protection can be defined as the prevention or minimisation of economical damage to crops caused by harmful species with a minimum of negative effects on the environment. Integrated crop protection focuses on sustainable production, producing high quality food and other products, diminishing the impact on the environment by minimising emission and damage to non-target biota caused by crop protection products and measures. Natural resources, regulating mechanisms and non-chemical control methods are used as much as possible to replace polluting inputs. Only the residual harmful species that are expected to cause economic damage to the crops are controlled with the input of pesticides. Minimising pesticide use provides adequate food safety. Residues on food products from the crop protection products used should be avoided or should at least be below the legal limits.

To design integrated crop protection strategies, a three-step approach is followed of 1) optimising prevention, 2) establishing the need of control and 3) choosing the actual control measures. Actual control measures are only taken after all other options in the previous steps have been used or considered. However in an ex ante design of the strategy, potentially unavoidable pesticide applications should be integrated in an optimal way into the strategy. Prevention, both on the strategic as on the tactical level, is considered the basis of integrated crop protection. Strategic measures are taken for a medium to long-term period and are often basic choices in the total farm design, as for example crop choice, rotation and agro-ecological layout of the farm. The tactical elements are usually short-term actions related to the cropping systems.

Figure 2 depicts the role of crop rotation in the prevention and control of pests, diseases and weeds (after Vereijken, 1994). Pests and diseases are placed along two axes. On the x-axis, the organisms range from non-mobile, mainly soil-born to very mobile, mainly airborne. On the y-axis, the organisms range from very specific (monofageous) to non-specific (polyfageous). Crop rotation is of increasing importance as the line moves from the lower right corner to the upper left corner.

1. Specific and non-mobile pests and diseases (upper, left corner): mostly soil-born, such as the cyst nematodes and *Rhizoctonia spp.* Infrequent planting of the organisms' favourite crop is usually sufficient to suppress these pests and diseases. The use of resistant and tolerant cultivars supports this approach.
2. Non-specific and non-mobile pests and diseases (lower left corner): these also mainly soil-born pests and diseases such as *Sclerotinia* and root knot nematodes. The composition of the crop rotation is important; which crops are grown and in which sequence. Support for this approach can be found in the cropping systems and cultivation measures (sowing or planting date, cultivar choice) depending on the organism involved.
3. Specific and mobile pests and diseases (upper, right corner): these are organisms such as *Plutella* and *Phytophthora*: classical crop rotation at the farm level is not helpful here, although spatial crop rotation can contribute to the control of semi-mobile, specific pests and diseases. Other solutions might be found in the cropping systems (cultivar choice, sowing or planting date, crop structure). Control measures during cropping might be necessary.
4. Non-specific and mobile pests and diseases (lower, right corner): many pests and diseases. Crop rotation is of little or no use, although crop diversification might be helpful. Again, the design of cropping systems and cultivation measures can contribute to prevention.

In these last two last cases, natural predators might help to protect the crop. Natural predators must be stimulated with a carefully designed and managed ecological infrastructure on the farm that offers year-round shelter and food (functional biodiversity). In addition, factors such as shape and size of fields and the total farm (parcel) layout are increasingly important, this is the agro-ecological layout of the farm.

The design of an optimal agro-ecological layout in time and space can be an additional preventive element. Its function is also based on prevention of monoculture in time and space. Additional criteria are formulated with regard to the layout such as adjacent fields, field size, field length and width, adjacency of subsequent crop rotation blocks and the ecological infrastructure (Vereijken, 1994). The adjacent fields in a crop rotation refer to the proximity of the same crop or the distance between crops belonging to the same group, both in time and in space. Plots with diversified vegetation in non-productive parts of the farm or in strips will generally result in enhanced diversity and abundance of natural predators. The specific species will vary depending on the diversity and availability of primary and alternative hosts or prey, location and size of the field, plant composition, floral diversity, surrounding habitat and land management technologies. The increase of natural enemies in fields can be achieved through for example hedgerows and field margins and sown strips of weeds.

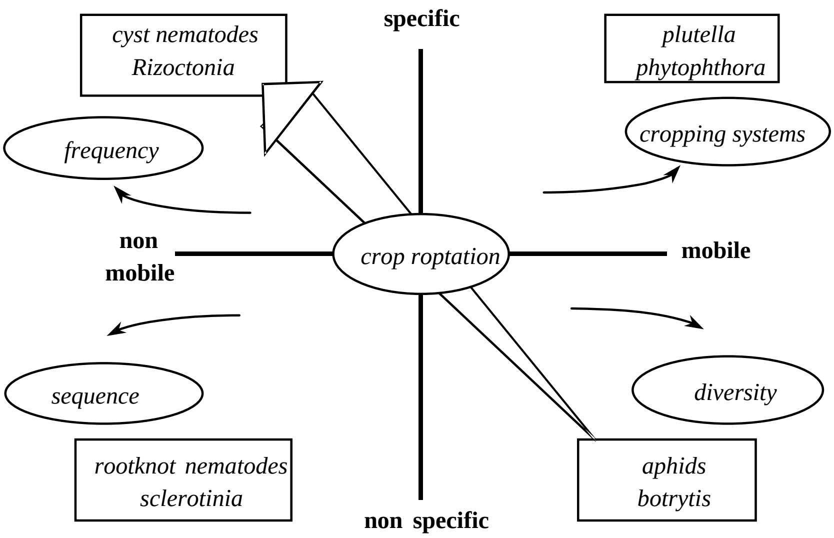

Figure 2. Effect of crop rotation against diverse classes of pests and diseases

Optimal nutrient management can help crop protection. Fertilisation levels that are too high as well as too low can cause the crop to be more susceptible to pests and diseases. High levels of nitrogen supply can influence the microclimate within a crop, which can cause a higher risk of infection of certain diseases.
Application of organic manure can have a positive effect on the anti-phytopathogenic potential of the soil. On the other hand, weed seeds might be imported with organic manure.
Farm hygiene is an important instrument to avoid or minimise the initial introduction of harmful species. This can completely eliminate infection or slow down their development.
Farm hygiene involves: Eliminating pest and disease survival in crop residues or on host plants by removing them; Avoiding contamination of fields and plants due to transport on machines, humans, or other means of dispersal; Avoiding initial introductions by using disease and weed-free seed or plants and organic fertilisers (composts, manure).
The second step in the integrated crop protection strategy is establishing the need of control. Preventive measures will not completely eliminate the occurrence of noxious organisms. However, their occurrence does not necessarily have to lead to economical damage. Appropriate tools (decision support systems) and expertise (diagnostic and monitoring skills) must be available and used to determine whether it is necessary or not to take any action to control these organisms. Regular crop inspection is the basis, followed by a prognosis of infestation or infection and economic loss. Only when economic loss is likely to occur, a treatment is necessary.

When the need to intervene is clear, the third step in the integrated crop protection method is to choose the most effective and practical action. However, treatments must also be judged on their environmental, ecological and economic merits. From an ecological and environmental point of view, physical (e.g. mechanical weed control, mulching, false seedbed) or biological control is generally preferred above chemical control. In chemical control besides efficacy,

reduction of emission and damage to non-target biota, selectivity and resistance management are important. Choices of pesticide, application technique and timing have to be optimal.
For every combination of a crop and harmful species, an optimal strategy can be designed consisting of the elements that are mentioned. Especially for the prevention elements of the strategies for different crops, it is vital that they are adjusted to each other in a complete strategy.

Experimental farms and projects with commercial farms
The methodology described above is tested on several experimental arable and vegetable farms and in several projects with commercial farms.
The first experimental farm were this methodology was tested was the Development of Farming Systems (DFS) experimental farm. The farm, which was started in 1979, is lying in the central clay area. As well arable crops (potato, sugar beet and wheat) as vegetable crops (onion, carrot and chicory roots) are grown (Wijnands & Vereijken 1992; Wijnands & Dekking, 2002). Other experimental farms with vegetables are located in Westmaas (southwestern clay area) and Meterik (southeastern sand area). At the experimental farm in Westmaas as well, a combination of arable and vegetable crops is grown (Sukkel & Garcia Diaz, 2002a; Sukkel & Rovers, 2002). At the farm in Meterik only vegetables are grown (Neeteson et al. 2003; Sukkel & Koot, 2002). Working on experimental farms only is not enough to get new strategies in practice. Working with commercial farmers is an indispensable step in the further dispersion of the new methods in the farming community. The latest project with commercial farms was the "Farming for the future" project (2000-2003). In this project, 33 farmers among nine vegetable farmers worked together with researchers and advisors on developing sustainable farming systems. Methods developed on the experimental farms were" practice-tested' on acceptance, efficacy, feasibility and practicability (Langeveld et al., 2004).

Results and discussion

Results on farm level, experimental farm
Figure 3 presents the overall results of the integrated system of the DFS experimental farm in the central clay area of the Netherlands as an average over the period 1992 until 1999. Parameter values reach or are at least close to the targets. The largest shortage is shown by the parameter net surplus in the theme farm continuity. Although financial results are comparable to average practice, the target for a financial sustainable system is not reached. Besides, small shortages are still present in the emission and damage of pesticides, the production quantity and the organic matter balance. The development of the integrated system is almost finished and dissemination of the system is possible (Wijnands & Dekking, 2002).
Table 1 presents data on parameters of the theme "clean environment pesticides" of three integrated systems at different experimental farms, developing integrated systems in the Netherlands, in 2001. The integrated system at the DFS farm (central clay area) contains 25% of vegetables (carrot and onion), the system at Westmaas (southwest clay area) contains 50% of vegetables (Brussels sprouts, iceberg lettuce, cauliflower, fennel and celeriac) and the system at Meterik contains 100% vegetables (iceberg lettuce, Chinese cabbage, leek and strawberry). At the integrated system of the DFS farm in 2001 all targets of the theme "clean environment pesticides" were met. At Westmaas, the damage parameters EYP-water life and EYP-soil life did not met the targets and at Meterik, the parameters for emission to the soil (EEP-soil) and damage to the soil life (EYP-soil life) did not meet the targets. Damage to water life was absent at the DFS farm because of wide cropping free zones (4,5 m) next to the ditches (part of the ecological infrastructure). Damage to water life was absent at Meterik because no ditches were present in

the system. Emission to soil was high at Meterik mainly because of the fungicide use in leek (Wijnands et al., 2003).

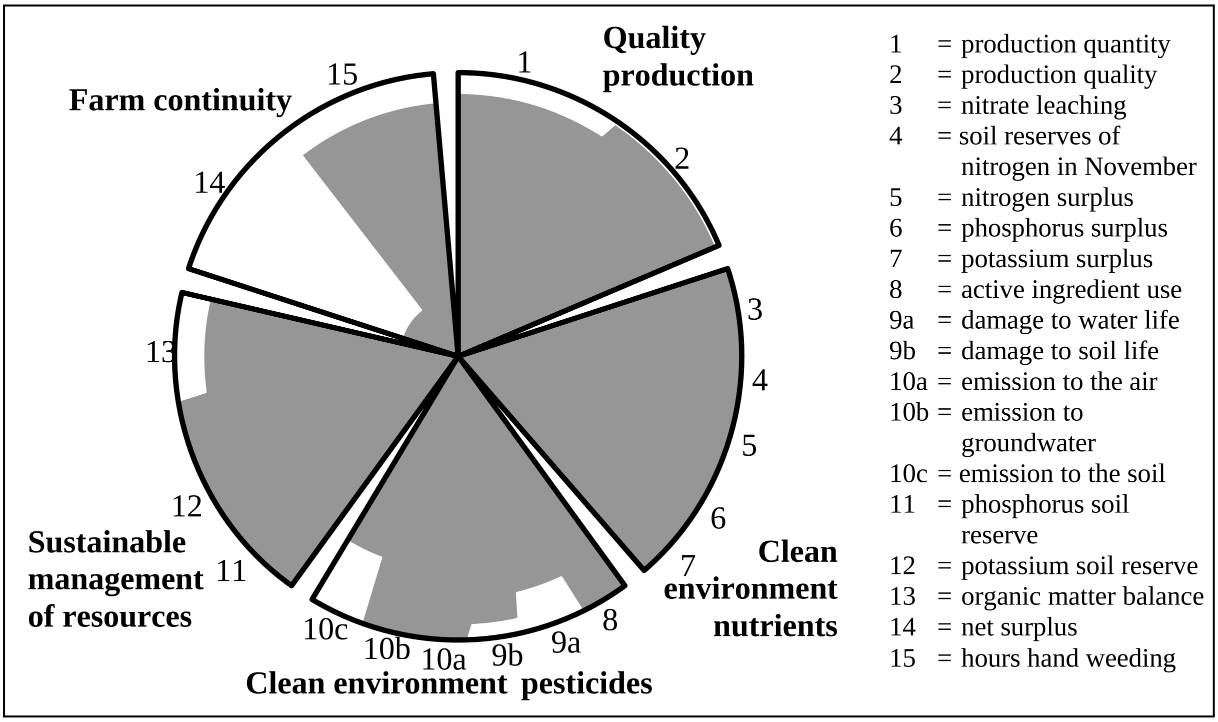

Figure 3. Average results on all themes of the DFS experimental farm (central clay area) in the period 1992 until 1999. Outer boundary of circle indicates the target for each parameter; the grey area indicates the actual result (Wijnands & Dekking, 2002).

Table 1. Emission and damage parameter values of the integrated systems of the experimental farms OBS (central clay area, 25% vegetables), Westmaas (south-western clay area, 50% vegetables) and Meterik (south-eastern sand area, 100% vegetables) in 2001; Figures are in italic when target value was met (Wijnands et al., 2003).

Parameter	**Dimension**	**Target value**	**DFS**	**Westmaas**	**Meterik**
EEP-air	kg/ha	< 0.7	*0.3*	*0.6*	*0.4*
EYP-water life	-	0% application > 10 points	*0*	72	*0*
EEP-groundwater	ppb	< 0.50	*0.15*	*0.22*	*0.3*
EEP-soil	kg days/ha	< 200	*101*	*193*	284
EYP-soil life	-	0% application > 100 points	*0*	9	9

Results in time DFS farm

Applying Integrated Crop Protection over a period of 20 year has resulted in a dramatic reduction in emission and damage of pesticides. However, not all targets are reached at all experimental locations, a large step forward was made. Figure 4 gives an example of the systems of the DFS experimental farm. The reduction amounted to between 80 and 99 % over 20 years. The main reasons for this large reduction were the abandoning of soil disinfection and the the substitution of old pesticides with high emission- and damage values with new ones with lower emission and damage values. Besides, development of integrated strategies to control pests and diseases and developments in mechanical weedcontrol (e.g. fingerweeder) contributed in lower values of the emission and damage parameters (Wijnands et al, 2003).

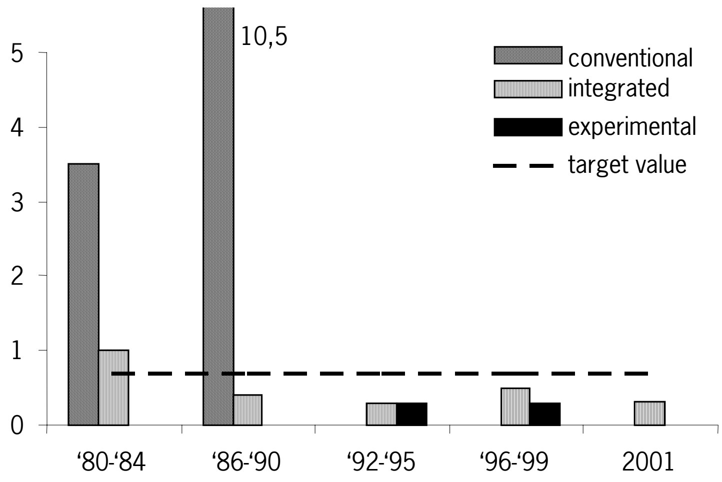

Figure 4. Parameter values of emission to air (a), damage to water life (b) and emission to groundwater (c) over 20 years at the DFS experimental farm (central clay area). In the whole period, an integrated farm was present; in the period 1980-1990 a conventional system served as reference; in the period 1992-1999 an experimental system was present (Wijnands et al., 2003).

Results of the vegetable farms in the "Farming for the future" project

During the "Farming for the future" project, it appeared to be possible to make a large step forward in the EEP-parameters compared to the situation before the project (Table 2). However, at commercial farms, the results are not as good as at experimental farms. The target values were in most cases more difficult to reach. Amongst the adopted measures were: leasing of land to extend crop rotation, use of more resistant cultivars, establishing the need of control and tolerating some damage, the use of mechanical weed control and false seed bed techniques, and last but not least the selection of pesticides based on the risk for emission and damage. Some problems remain, since there are either no practicable non-chemical methods or alternative chemicals available. The financial stakes are high in vegetable growing, therefore farmers are cautious with new techniques that may endanger product quality or quantity that causes too often pesticide application as insurance and narrow crop rotations that cannot be widened from an economic perspective (Anonymous, 2001; Anonymous, 2002).

Discussion and conclusions

Farming system research is target-oriented research with a wide outlook on the future to be able to develop the farm of the future. Targets are quantified to be able to determine the value of the strategies.

A proper crop rotation is the basis for every more syustainable farming system It lays the basis for other methods such as crop protection. Nowadays the manyfold possibilities of crop rotation are hardly used to solve problems.

We demonstrated that with a strategic and system based approach as used in farming systems research large steps can be made towards more sustainable systems.
The total system approach is an indispensable step in the development of an individual crop protection technique to implementation of this technique in practice. Therefore more cooperation is needed between specialists on certain crop protection aspects and the generalist system researchers. Only then the development of more sustainable crop protection in special and farming systems in general can be really succesful.

Table 2. Average values of the emission and damage parameter values of two groups of vegetable farms in the project “Farming for the future” before the project (average 1997 until 1999) and in 2001; the group in Brabant consist of 4 farms, the group in Limburg of 5 farms; Figures are in italic when target value was met (Anonymous, 2001; Anonymous, 2002).

Parameter	**Dimension**	**Target value**	**Brabant**		**Limburg**	
			97-99	**01**	**99-97**	**01**
EEP-air	kg/ha	< 0.7	2.1	1.2	1.0	*0.4*
EYP-water life	-	0% applications > 10 points	-	26	-	31
EEP-groundwater	ppb	< 0.50	30.3	1.7	3.7	1.4
EEP-soil	kg days/ha	< 200	1646	653	681	340
EYP-soil life	-	0% applications > 100 points	-	7	-	25

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Appendix: Environments Exposure to Pesticides (EEP)

EEP calculates per pesticide application the potential pesticide emission to the compartments air, soil and groundwater. Calculation of this potential emission is based on the amount applied active ingredient and physical pesticide properties (Sukkel & Garcia Diaz, 2002b.)

The EEP basic data are:

DT50	=	soil half life, a measure of the persistence in the soil
Kom	=	the partitioning coefficient of the pesticide over the dry matter and water fraction of the soil/organic matter fraction of the soil to organic matter
VP	=	vapour pressure; a measure for the volatilisation in Pascal

Derived from this basic data is:

F = the F value, a measure of the fraction of the active ingredient that leaches

F = exp (-[(A x fom x Ln2 x Kom) / DT50 + (B x Ln2)/DT50 + C])

In which:

A = 392.5 L kg^{-1} $days^{-1}$; B = 68.38 days; C = 1.092 and Kom = 0.0146 (van der Zee en Boesten, 1991)

Emission % = the translation of vapour pressure to the percentage of the active ingredient that volatilises, the emission percentages are:

> 10 mPa	95%
1 – 10 mPa	50%
0.1 – 1 mPa	15%
0.01 – 0.1 mPa	5%
< 0.01 mPa	1%

EEP calculation formulas for an application of one pesticide are given below. The Σ_{1-n} refers to pesticides with more than one active ingredient. Then, the calculations should be done first per active ingredient and then added per parameter to make a total for the application.

EEP-air [kg ha^{-1}] = Σ_{1-n} *(a.i.* $input_m$ *x* $emission\%_m$ */100)*

In which:

a.i. $input_m$	=	input of active ingredient *m* x active ingredient concentration of active ingredient *m* in a pesticide [kg ha^{-1}]
$emission\%_m$	=	emission percentage of active ingredient *m*

EEP-groundwater [ppb] = Σ_{1-n} *(a.i.* $input_m$ * F_m */ prec surplus)*

In which:

a.i. $input_m$	=	input of active ingredient *m* x active ingredient concentration of active ingredient *m* in a pesticide [kg ha^{-1}]
F_m	=	F value of active ingredient *m*
prec surplus	=	precipitation surplus [m^3]

EEP-soil [kg days ha^{-1}] = Σ_{1-n} *(a.i.* $input_m$ *x* $DT50_m$ */ ln2)*

In which:

a.i. $input_m$	=	input of active ingredient *m* x active ingredient concentration of active ingredient *m* in a pesticide [kg ha^{-1}]
DT50	=	soil half life of active ingredient *m*

From the amount of active ingredient per application, the EEP value per application can be calculated.
EEP values per application can be summed per compartment to calculate EEP values on crop, field or farm level.