Integrated and ecological crop protection

VEGINECO Project Report No. 4

VEGINECO
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The Netherlands Italy Spain Switzerland

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1 Introduction

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1.1 Vegetable production in Europe: shortcomings and new farming systems

Although vegetables cannot be said to be a key issue within European Union market policy or political discussion, they are, nevertheless, a major constituent of the daily diet of hundreds of millions of European citizens. 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 relatively small, and are mostly concentrated in certain regions (for practical, market-oriented reasons). These farms are characterised by very intensive land use (all-year round soil utilisation) and high (external) labour requirements per hectare. The result is that there is almost no 'space' to include nature and landscape elements. Because the number of crops on a farm is limited, crop rotations are short and host crops are present all-year round in a very small geographical area. The consequence of this is that crops are under the constant risk of being decimated by pests and disease. This situation causes the intensive, but increasingly ineffective, use of pesticides. Another factor contributing to the intensive use of pesticides and also of nutrients is the need to achieve high yields and ever-increasing 'cosmetic' quality requirements, forced on the industry by very highly competitive international markets.
Because the costs of nutrients and pesticides are relatively low compared to the market value of the crops, there is little economic incentive to reduce these costs and the inputs. The high inputs are seen an 'insurance policy'. At present, vegetable-growing farms are experiencing very large fluctuations in profitability, especially large downturns. The future looks even gloomier if the need for (socially acceptable) wage increases for hired labour and increasing overproduction (due to free market competition) are also taken into consideration.
Consumers are worried about health risks connected to agricultural products, and, in particular, to the nitrate content, pesticide residues and contaminants in fresh vegetables. They are also concerned about the adverse effects of high nutrient inputs on the environment and the growing lack of concern for nature and landscape. There is a growing public demand for production methods that have an 'ecological content'. The dilemma is that consumers are also demanding high quality products at the same time. In addition to consumers, government authorities, in their policies and efforts, are addressing exactly the same issues. Finally, retailers and other partners in the markets are increasingly searching for 'certified environmentally-friendly products'.
This means that farmers are no longer being asked to only produce inexpensive food in large quantities, but are currently being challenged to also be responsible custodians of rural areas, or the green spaces. At the same time, they are also required to produce high-quality (speciality) products. The repercussions of these demands are influencing the entire depth and scale of farm management.
There is an urgent need for new multi-objective farming systems that integrate into the old objectives 'new' aims such as product quality coupled with quality in production methods; maintain the quality of the a-biotic environment; increase the quality of the surrounding natural areas and countryside, and agronomic sustainability. For this to take place, 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 of these new objectives. In redesigning these methods, the key issues in farming are involved, such as crop rotation, crop protection and nutrient management. In addition, new strategies for nature and landscape development are urgently required. All these different aspects need to be integrated in safe, efficient, acceptable and manageable strategies. At the farm level, this can only be done within the context of a farming system.
At present, there are two major visions with respect to integral approaches towards agriculture: integrated and organic farming systems (I/OFS). Integrated production is slowly growing in importance, and integrated labels have been introduced in a number of European regions and countries. The development of these labels is still in progress, but, too often, it is only based on single factor research. A consistent research base in comprehensive farming systems, and on the potential and possibilities for integrated production, is lacking. Switzerland is possibly the only exception because as early as the end of the eighties, large-scale pilot projects were carried out in this country, which resulted in detailed food production guidelines.
For organic production, national labels have long been available and have recently been brought into line with the European directive on organic farming (EU 2092\91). The current objective of organic farming is to use no pesticides or chemical fertilisers at all. The emphasis is on what should not be done, rather than on stressing the positive objectives for protecting the environment or caring for nature and landscape.
Both systems have not yet been fully explored or exploited and need to be developed further before a proper evaluation can be made of their potential contribution to the future of European agriculture.

1.2 VEGINECO: Farming systems research on field grown vegetables

Objectives and research method

Within the framework of the EU FAIR programme, a project was set up to develop integrated and organic farming systems for outdoor vegetable farming systems. The overall objective of this project was:

'to develop integrated and organic outdoor horticultural farming systems that are more sustainable in agronomic, environmental, ecological and economic terms, and that ensure high quality products that minimise environmental and health risks, thereby meeting market demands'.

This EU project focused on research into farming systems to develop, test, evaluate and compare prototypes of integrated and organic vegetable farming systems in four important vegetable-producing regions in Europe, selected to represent different socio/economic, soil and climatic conditions. These regions were: the clay region in the South-western area of the Netherlands, Emilia-Romagna in Italy, and the Valencia region in Spain. Additionally in Switzerland, organic and integrated pilot farms were compare and improved.

In this project, the prototyping methodology of designing, testing, improving and disseminating new 'farming systems' (Vereijken 1994, 1995) was applied and improved. It was a combined research and development effort, taking as its starting point a profile of agronomic, environmental and economic demands (objectives) for more sustainable, future-oriented farming systems. The end product was a number of tested prototypes, ready and available for widespread application.

Participants in this farming system research

Applied Plant Research (P.P.O., formerly P.A.V.), Lelystad, the Netherlands (project co-ordinator)
PPO has been involved in farming systems research since 1978. For the VEGINECO project, PPO tested integrated and organic vegetable systems in the South-western clay region of the Netherlands. The integrated systems consisted of eight variants of integrated vegetable systems in which arable and intensively or extensively grown vegetable crops were combined. The integrated system variants were aimed at direct practical implementation to achieve optimal economic results, whilst the organic system was focused more on experimental freedom to explore the environmental and agronomic potential of the system.

Centro Ricerche Produzioni Vegetali (C.R.P.V.) soc. coop. a.r.l. Cesena, Italy (Emilia-Romagna)
C.R.P.V developed and tested two types of integrated systems and one type of an organic system for this project. All the systems were located in the Emilia-Romagna region. To reflect the situation of small farmers accurately, the organic system and one of the integrated systems were based on fresh vegetables. The other integrated system, aimed at larger farms, focused on integrating arable and horticultural activities.

Instituto Valenciano de Investigaciones Agrarias (I.V.I.A.), Moncada (Valencia), Spain
I.V.I.A. developed and tested five integrated systems and one organic system for this project, based on the small-scale production of fresh vegetables. To form a representative sample, the integrated systems included enterprises spread over the entire Valencia region. The location (Paiporta) and rotation system of the organic system was identical to one of the integrated systems.

Eidg. Forschungsanstalt fur Obst-, Wein- und Gartenbau, Wädenswil (F.A.W.), Switserland
F.A.W. performed 'on-farm research' at 14 private pilot farms scattered over the country – seven integrated farms and seven organic farms. By monitoring the practices and results at these selected farms, a clear picture emerged of their differences. This made it possible to target specific elements in need of further development and to introduce improvements in these areas into farm practice.

VEGINECO publications

This VEGINECO method manual is one of a series of publications resulting from the VEGINECO project. VEGINECO specialises in producing tested and improved multi-objective farming methods for key farming practices – e.g. crop rotation, fertilisation and crop protection – to facilitate the integration of potentially conflicting objectives like economy and ecology. In addition to improving 'old' practices, new methods have been developed to integrate environmental concerns in the field of nature and landscape management with current farming practices. A manual deals with each method in depth. An extensive description of prototyping methodology is included in the manual on crop rotation. In addition to these methodological manuals, other publications include workshop proceedings and a final report on the VEGINECO project. The workshop proceedings focus on project results in general and their implications for policy and certification. The final project report concentrates on the results of the prototyping methodology, in terms of application and development, and how well the tested systems performed.
This report describes a methodology for developing nutrient management strategies. In addition, examples of its application under different conditions in Europe are presented.

1.3 Prototyping methodology

For the development of these sustainable vegetable-farming systems, a standardised methodology called "proto-

typing” was used. 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.
The prototyping methodology was examined for arable farming in a four-year European Union Concerted Action (Vereijken, 1994 and 1995). For vegetable farming, however, this type of research is limited.
The methodo-logy of prototyping is still young, dyna-mic and developing. However, it can be described as an innovative process in 4 steps: analysis and diagnosis, design, testing and improving and dissemination (Figure 1.1).
The process of prototyping starts with a regionally based analysis and diagnostic phase that includes the following aspects: sectorial statistics, farm structure, agro-ecological state-of-the-art, ecological–environmental impact, the socio-economic situation, trends in structural changes and current political conditions.
Based on an analysis of shortcomings in current farming methods and of future perspectives, the design phase starts by establishing a hierarchy of objectives for all-round sustainable farming systems.
In the VEGINECO prototyping practice, these rather abstract objectives are translated into five directional themes: quality production, clean environment, attractive landscape and diversified nature, the sustainable management of resources, and farm continuity.
In order to quantify the objectives of a theme, each one is fixed within a number of farm-level parameters. Each parameter is given a target value so that a well defined, documented and clear framework can be established to design, test and improve farming systems. The target levels are future oriented and are derived from legislation, scientific evidence or expert knowledge.
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). In most cases, these methods need further development if they are to realise their objectives.
To create a basic framework for interpreting the results, the next step in the methodology is to design a theoretical prototype to link the parameters with the methods. It then becomes possible to check the links. 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 next phase is testing and improving the farming system that has been designed. For the test phase to be successful, a farming system has to be laid out in time and space. Important here is the choice, not only of a multi-functional crop rotation, but also of the agro-ecological identity of the farm.
When the prototype shows stable results at the level of the parameter targets, the next logical step is dissemination. The perspectives of a new prototype can only be evaluated in practice. Management is the key factor for the success and feasibility of these new approaches. Therefore a region-specific prototype, developed on experimental farms, is first tested on a small number of pilot farms. This is considered an indispensable step before new prototypes are introduced on a large scale.

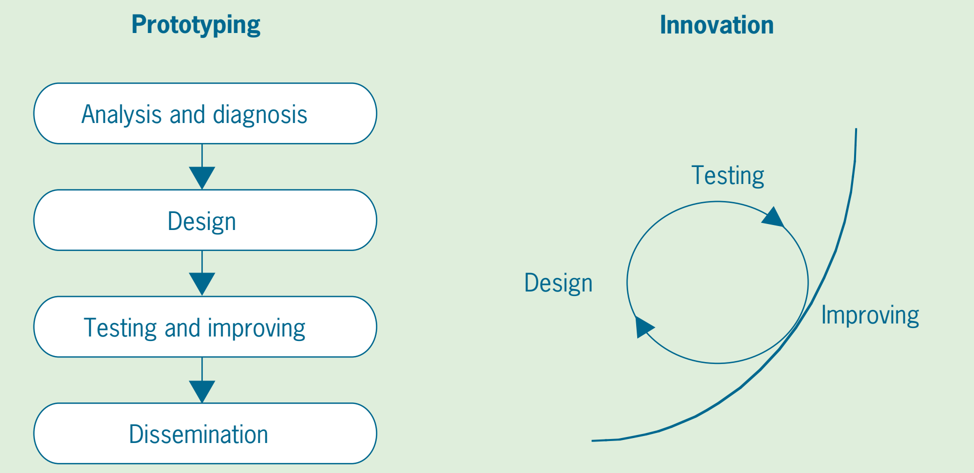

Figure 1.1 Prototyping methodology and the innovation cycle

2 Integrated and Ecological Crop Protection (I/ECP)

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2.1 Analysis and diagnosis

2.1.1 Crop protection and pesticide use in Europe

In modern agriculture, crop protection has become increasingly synonymous for pesticide use. The use of pesticides in Europe varies strongly in each country (Figure 2.1) and for each crop.
The total use in the European Union is about 300 000 ton (1996). Fungicides make up the largest pesticide group sold in the 15 countries of the European Union, accounting for 41% of total weight of active ingredients in 1996, followed by herbicides (39%), insecticides (12%) and other pesticides (8%) (http://europa.eu.int/comm/agriculture/envir/report/en/pest_en/report_en.htm). However the situation varies from one country to another due to different climatic conditions and different types of crops. For example, in countries in which a large quantity of cereals is cultivated, pesticide input tends to be much lower.

Specific data on the use of pesticides in field-grown vegetables does not exist for most countries. However, the estimated active ingredient input for field-grown vegetables is expected to be at least equal to the average input in agriculture considering crop intensity and the large variety of harmful organisms.

Despite all efforts to reduce pesticide use, the total use is rather stable especially for fungicides and insecticides:

- A high intensity of cultivation and narrow one-sided rotations resulting in an increase in pest and disease pressure, especially from soil-born pests and diseases.
- Decreasing effectiveness of pesticides caused by more resistant pest, disease and weed populations.
- The introduction of new exotic pests and diseases.
- Market standards demanding stable and high cosmetic quality.
- The relatively bad economic situation of vegetable farmers combined with the absence of financial incentives to reduce pesticide use.
- Relatively low costs for pesticide input compared to the high value of the crop and high risks for complete crop loss caused by pests and diseases.

Pests and diseases can cause very high or complete yield and quality losses in vegetable crops. Small defects in the product can make the product unmarketable. These high quality demands and the large financial risks cause most farmers to use very conservative crop protection strategies with low risks.

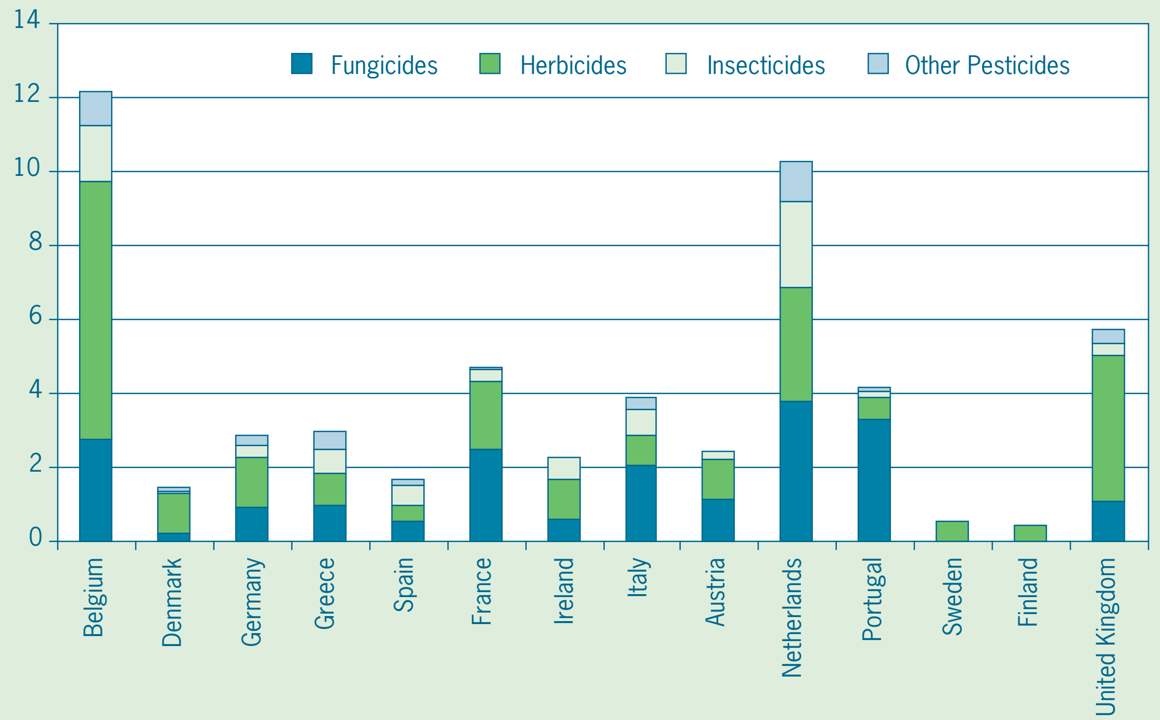

Figure 2.1 Pesticide use per hectare in 1996 (kg ha^{-1}) in agriculture in EU countries (http://europa.eu.int/comm/agriculture/envir/report/en/pest_en/report_en.htm)

In general, production of vegetable crops has been increasingly rationalised for the past decades in Europe. Scale enlargement, specialisation, increase in level of farmers' expertise and restrictive legislation are the leading factors for this development. However, there is still a large dependency of pesticides mainly because the risks of financial yield loss are high compared to the costs of the pesticide input. Frequent periodic treatments are commonly used against many pests and diseases, and when effective pesticides are available, the cultivar choice is more based on their potential yield and quality than on their resistance to pest and diseases.
This dependency is stronger in the Mediterranean countries, such as Italy or Spain, than in Northern Europe. The warmer climate in southern countries and, therefore, the possibilities for all-year round crops are important because of the higher pressure of pests and diseases. Soil disinfections are normal practice in the most intensive areas. In addition, the small size of fields and a lack of adequate machinery are usually the biggest obstacles for mechanical weeding.

In Northwestern Europe, the weed control in field-grown vegetable crops tends towards the use of mechanical control and the use of low dose systems. However, there is still a preference for the use of herbicides compared to mechanical control. In agriculture, the use of herbicides in the Netherlands has been reduced 33% in the last 15 years (anonymous 2001). Concerning fungicides and insecticides, pesticide use has been stable for the past decade. The humid Dutch climate, world market prices and quality requirements makes farmers more dependent on the availability of fungicides. The application of fungicides and insecticides in practice is the balance between a rational control based on observations and weather conditions, and a preventive control as an "insurance policy". The use of chemical soil disinfection has been reduced with 88% in the past two decades mainly because of restrictive legislation.

2.1.2 Undesirable side-effects of pesticide use

Pesticide use has many undesirable side effects such as emission, damage to non-target biota and risks for human health. These side effects are discussed in more detail in this section.

Emission to the environmental compartments air, soil and water

Volatilisation is the major cause of pesticide loss. Volatilisation losses up to 80-90%, within a few days after application, have been reported (Taylor and Spencer, 1990). A study in the Netherlands (as part of the evaluation of the crop protection policy) estimates that some 50% of the total pesticide used volatilises (Anonymous, 1996). What happens to pesticides in the atmosphere is relatively unknown. However, atmospheric transport and deposition (global distillation) may distribute many pesticides all over the earth (Schomburg and Glotfelty, 1991; Gregor and Gummer, 1989; Atlas and Schauffler, 1990; Simonich and Hites, 1995).
Pesticide concentrations exceeding the permitted amount are regularly found in ground and surface waters. A study in four countries within the European Union (Isenbeck-Scröter et al. 1997) shows that the pesticides most frequently detected in water analyses are ***atrazine***, ***simazine*** and ***bentazone***.

Damage to non-target biota

The presence of pesticides in the abiotic environment is potentially a threat for all of the biota (non-target). The magnitude of this threat is only partially known and quantification is difficult because of the several emission routes. Although the poisoning of non-target wildlife is regularly recorded (water life, birds, predators), a proper evaluation of the ecotoxicity of a substance is virtually impossible since it involves thousands of different species that react differently when exposed to a certain substance. It does not only involve direct toxicity but also mid-term and long-term effects on, for instance, fertility, vitality and population dynamics.
An indirect effect of pesticide use is the selection of resistant and competitive genotypes, which out-compete non-target species. The selection of aggressive and resistant weeds by the intensive use of herbicides has been reported to influence biodiversity in field margins and hedgerows.

Risks for public health

The risk for human health due to pesticides use is different depending on the population. The groups with the highest risk are farmers and other professionals working with the pesticides. On the other hand, a distinction can be made between acute and chronic toxicity, which mainly depends on pesticides characteristics, and amount and length of exposure.
In the last 10-15 years, another long-term effect has been detected for certain pesticides. It is the endocrine disruption, and it can be summarised as the capacity of certain pesticides and other compounds to change the hormonal equilibrium (endocrine functions) affecting the health of an organism or its offspring. Exposure to endocrine disrupting chemicals is particularly serious for pregnant or nursing women and their developing foetuses or babies (Smolen, 1996). Legal measures are expected to be taken concerning these kinds of substances in the near future. It could lead to a major change in the environmental concept of the pesticides.
On the other hand, Public Administrations regulate pesticide use and set MRLs (maximum of residue level) for the authorised pesticides on crops to decrease the risk of pesticide contamination. The main problem with MRLs is that there are many differences between the legislation among the different countries, and many times, this can be an obstacle for international trade. Legislation within the EU member states is continuously progressing because the residue limitations are being brought into

line. Control programmes are usually run to control that these residues are not higher than permitted amounts. According to different vigilance plans set up in several European countries (Coscollá, 1999), the range of samples with residues above the MRL is from 0.7% (Germany '96, national market of fruits and vegetables) to 9.3% (Finland '97, imported fruits and vegetables). In every case, the amount of samples with residues is always much higher. For example in the Valencian region of Spain, the average percentage of samples with pesticide residues was 56.2%, and samples with residues over the MRL were 2.6% (SSCV de Silla, 2001). In every case, these figures are useful only as an estimate for two reasons: the difficulties in analysing the methodology and not all the compounds are usually analysed.

2.1.3 Policy, legislation and label guidelines

Policy and legislation

The current EU policy, in particular directive EU 414/91, and most of the EU countries pesticide policies focus on regulations, which define minimum requirements and the same standards for quality, and application of agricultural pesticides. The uniform EU principles for the admission procedure were set in 1994. Maximum levels were set for factors such as persistence, risk of groundwater contamination and the bio-concentration factor. The progress of EU legislation being implemented into national legislation is continuing very slowly.

The EU intends to add pesticide policies in addition the current regulatory framework. Under the EU's Fifth Environmental Action program (1992), the EU has set for itself the objective of achieving by 2000 a "significant" reduction of pesticide use. Actions identified as necessary to reach the target are registration of sales and use of pesticides (EU 414/91). There is also a move towards policies that aim to provide assistance to agriculture, targeted to specific (environmental) outcomes (cross compliance, agri-environmental programmes). Payments or other financial benefits to farmers for environmental purposes are increasing (for instance, Council Regulation 2078/92 EC about agro-environmental programmes).

EU Directive 83/91 of 3 November 1998 on the quality of drinking water has set the maximum admissible concentrations of each substance at 0.1 ppb and the total concentration of all pesticides at 0.5 ppb. Concerning food safety, the EU guidelines EU 642/90 and EU 362/86 standardise the residue tolerance of pesticides in foodstuff.

Pesticide use in organic production in Europe has been regulated in Council Regulation EU 2092/91 (revised by Commission Regulation EU 436/2001).

At a national level, diverse action plans have been or are running to reduce pesticide use in Sweden, Denmark, Finland, Austria Switzerland, and the Netherlands. All pesticides are re-evaluated in line with the European standards for application of pesticides. This means that the number of allowed pesticides will decrease and the most environmentally harmful applications will be eliminated. The aims of the policies concerning pesticide pollution are the reduction of dependency, emission and damage. These policies have resulted in legislation, subsidies and agreements within the agricultural sector.

The MJPG policy in the Netherlands, completed in 2000, involved an agreement with the agronomic sector to reach certain targets for pesticide use and emission. One of these targets was the reduction of pesticide use by 40% from 1995 to 2000. Based on the evaluation of the MJPG policy, a new policy is being developed for the coming period, which possibly will include tax benefits for farmers who can fulfil certain requirements for pesticide use. There is also legislation being developed (probably active starting in 2002) which requires a licence for production. This legislation involves certification of producers, complete registration of pesticide inputs and restrictions on pesticide use.

In Switzerland, the federal board for agriculture supports different eco-programmes, for example, the IP-program and the Bio-program. The legislation consists of article 31b of the law for agriculture and it establishes that by 2005, 90% of all farms should be registered as integrated or organic producing farms. The reform of agricultural policy in Switzerland ("Agrarpolitik 2002") requires the farmers to fulfil some requirements in order to receive direct payments. These requirements are connected to common integrated farming practices. For instance, chemical soil disinfection is not allowed.

Integrated labels

There are several IP labels in the EU countries, promoted either by the Public Administrations or the supermarket chains. Crop protection is established in these protocols by creating for each crop a short list of pesticides that can be used and others that can only be applied with restrictions. Recording all farming activities is required, especially pesticide applications (even those applied after the harvest). Other important requirements are connected to protective clothing for working with pesticides, spray equipment (annual calibration is needed), residues analysis, pesticides storage, and handling of empty containers and obsolete pesticides. In general, nothing is stated about specific limitations of pesticides inputs or residues.

Nevertheless, not all field-grown vegetables have specific protocols in every EU country. Furthermore, requirements can vary quite a lot within the different labels because there is no international standard for integrated food production. The new EUREP GAP protocol for Good Agricultural Practices is the first attempt to standardise one IP label in Europe. Some European retailers (mainly Dutch and British) have targeted the EUREP GAP label to become a reference point for the near future. The protocol has been set out for the global production of horticultural products. Therefore, the requirements are very general and based on national legislation. As legislation in different European (and world) countries on crop protection is diverse and standardisation is continuing very slowly, EUREP GAP lacks a solid base of requirements and different interpretations will appear. However, certain basic elements for crop protection are required in certification schemes:

- Attention to prevention such as choice of appropriate crop or variety, crop rotations, use of resistant varieties, creation of habitats for the beneficial predators, and good hygienic practices.
- Methods to determine when action is required.
- Preference of non-chemical methods (cultural, physical and biological) over chemical methods.

For example, according to EUREP GAP 2001, "growers must…seek to employ crop rotations whenever practicable". Furthermore, "where rotations are not employed, growers must be able to provide adequate justification". The chemical fumigation of soils will be avoided wherever possible.

In some Dutch labels, there is a maximum of active ingredients input at a crop level (MBT or milieukeur). In other cases, the chemical disinfections of soils are not allowed (MIGROSsano and SGU in Switzerland, and regional guidelines of Murcia in Spain). In other cases, these labels limit the level of pesticides residues to under the 50% of the MRL, such as NATURANE in Spain.

Organic labels

Most labels for organic production in EU are based on EU Regulation 2092/91. In general, this regulation treats several topics in a general way and, therefore, it is submitted to different interpretations that will be reflected in national guidelines. For example, in the list of authorised "bio-pesticides", the use of some (copper or ***azadiractin***) is conditional based on the need to be recognised by the inspection body or authority. The protection of natural predators will have to be reinforced through the "care of hedges, nests, and so on" (different interpretations may appear). Genetically modified organisms or the derivatives are specifically banned in organic farming. The list with approved organic pesticides differs between countries. Some pesticides will be forbidden in most countries due to the negative effects on both the environment and human health such as copper, ***metaldehyde***, mineral oil and ***nicotine***. In almost every case, most organic pesticides somehow affect not only the environment and human health, but also the equilibrium of the farming systems.

In the Netherlands, the pesticide policy for organic farming is stricter than in other countries. For instance, copper is allowed in all partner countries except the Netherlands, although a reduction in use is predicted. In Switzerland, only non-synthetic (natural) pesticides registered in an official list (FiBL, 2000) can be used if cropping strategies and biological control are not successful.

2.2 The theoretical background of IECP

Definition

Integrated and Ecological Crop Protection (I/ECP)
Integrated/ecological crop protection is the prevention or minimisation of economical damage to crops caused by harmful species with a minimum of negative effects on the environment.

Integrated and organic 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 and regulating mechanisms 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 emission and damage provides adequate food safety. Residues on food products from the crop protection products used should be avoided or at least be below the legal limits.
The terms "integrated and ecological" in the method name stands for the prototype in which the crop protection method is used. The general principles of the method are basically the same for prototypes of both organic and integrated farming systems. The difference is that in organic systems, contrary to integrated systems, no "synthetic" pesticides are used. Therefore the focus of the crop protection methods can be on different factors for different prototypes.

Connection to other farming methods

Crop protection does not function independently of other farming methods. In addition to Nutrient Management and Ecological Infrastructure Management, Multifunctional Crop Rotation (MCR) interacts closely with I/ECP. In defining the rotation of a farming system, the basis is laid for optimal prevention against pests and diseases based on the choice of crops and varieties and the layout in time and space.
The relationship of I/ECP with Nutrient Management is laying in the growth of healthy crops: both nutrient deficiency and surplus can make crops susceptible to pests and diseases. Ecological infrastructure Management influences I/ECP by giving food and shelter to beneficial and/or harmful species.

Relationship with different themes
The themes criteria used to assess the performance of farming systems were given in paragraph 1.2. Crop protection has a strong relationship with the themes quality production, farm continuity and clean environment.

- Clean environment is strongly influenced by the emission of pesticides in different environmental compartments and by the damage that can be done to non-target species.
- Quality-production is influenced by the prevention of yield and quality reduction by harmful species, pesticide damage to the crop (herbicides) and pesticide residues on the product.
- Farm continuity is influenced indirectly through the effect on quality production and directly by the costs of crop protection and extra labour input (manual weeding) caused by insufficient crop protection.

In addition to these main relationships, crop protection can influence 'sustainable use of resources' by the accumulation of pesticide residues in the soil (for example, copper). Also the management of the natural habitats on farms can influence crop protection because natural enemies can use it for food and shelter. In Annex 2, an overview shows the common set of parameters.

2.3 Design of crop protection strategies

2.3.1 Main elements of an integrated strategy
To design crop protection strategies, a three-step approach is followed. These steps should be followed in sequence. The last step, actual treatment or control measures, is only taken after all other options in the previous steps have been used or considered.

1. Prevention:
   a. Strategic:
      - farm hygiene and legal measures,
      - agro-ecological lay out and crop rotation,
      - stimulation of bio-diversity,
      - soil structure and water management.

   b. Tactical:
      - variety of choice,
      - healthy seeds and plant material,
      - adapted planting time or plant spacing,
      - optimal nutrient supply,
      - soil cultivation.
2. Establish need of treatment:
   a. Regular crop inspection.
   b. Prediction of economic loss (thresholds, guided control systems).
3. Treatment measures (crop protection: physical, biological and chemical):
   a. Non-chemical.
   b. Chemical:
      - pesticide choice,
      - dose, timing and technique.

Prevention is considered the basis of integrated ecological crop protection. In prevention, strategic and tactical elements can be distinguished. Strategic measures are usually long-term and are often basic choices in the total farm design. Crop choice, rotation and agro-ecological layout are some of these strategic elements. The tactical elements are usually short-term actions mostly in connection with the cultivation technique.

Structural elements (preventive measures) will not usually completely eliminate the occurrence of noxious organisms. However their occurrence does not necessarily have to lead to economical damage. Appropriate tools and expertise 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 basic action.

In the end, when the need to intervene is clear, the most adequate action must be chosen. Of course, treatments must be effective and practical. However, treatments must also be judged on their environmental, ecological and economic merits. From an ecological and environmental point of view, physical or biological control is generally preferred above chemical control.

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 structural elements of the strategies for different crops, it is vital that they are adjusted to each other in a complete strategy. The different possible elements of integrated crop protection strategies are treated in detail in the next section.

2.3.2 Prevention
Prevention can be summarised as measures for reducing the probability of damage. The so-called preventive pesticide inputs are not included in prevention strategies. Next the main elements of prevention will be treated below:

1. Prevention of initial inoculum:
   - legal measures,
   - farm hygiene and healthy seeds and plant material.
2. Enhancing (bio) diversity:
   - crop rotation and variety choice,
   - design of the agro-ecological layout,
   - other means of bio-diversification.
3. Creating unfavourable conditions for noxious organisms:
   - cultural methods,
   - nutrient management.

Legal measures
All the members of the EU have legislation to eliminate introduction of new exotic organisms and dispersal in their countries. With the elimination of borders in the EU, this legislation has become even more difficult to regu-

late. At this time, the EU legislation should be capable of eliminating introduction of these exotic organisms as much as possible and their possible dispersal through the different countries.

There are many examples of the import of exotic organisms: *F. occidentalis* in vegetable crops, or *P. citrella* in citrus crops are some the most recent and most important cases. At the same time, new viruses are continuously appearing almost every year. Rigid and strict legislation could save a lot of money and make the farming systems more sustainable. For this legislation to become more efficient, it is necessary to have (Ripollés, 1988):

- an actual and clear legal base,
- public services that can regulate this legislation quick and efficiently,
- appropriate technical and economic means.

The two most important legal means for prevention are quarantines and inspections of nurseries.

Farm hygiene, healthy seeds and plant material

Farm hygiene and the use of healthy seeds and plant material are important instruments 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).

Legislation only partially guarantees the use of healthy and disease-free material. Some pests and diseases cannot be detected on seeds and planting material. For other harmful species, it is not required to deliver disease-free plant and seed material. Careful selection of especially vegetative propagated crops and plantings can be very useful.

Crop Rotation and variety of choice

The main cause of the high pressure from and the fast propagation of harmful species is the cultivation of continuous monocultures. Crop rotation on farms can be highly effective to break this monoculture in time and space. The main principle is to follow one crop by another genetically unrelated one so that the pests of the first crop are unable to feed or propagate on the following crop. This means diversification at the farm level between plant families and/or plant species, or even between plant varieties. However, such techniques may or may not coincide with good agronomic practices and each case must be decided on its own merits. The composition of the cropping plans, the order of the crops in the rotation, the numbers of years between crops of the same family, species or varieties are factors that need to be considered

Figure 2.2 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. Specialised nematodes, such as the potato cyst nematode, can be controlled well with crop rotation.
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 crop-

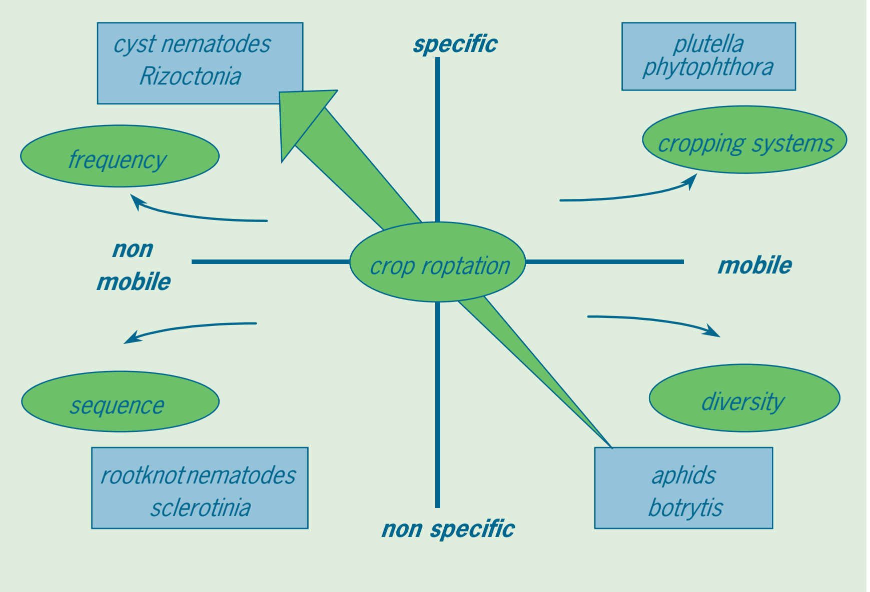

Figure 2.2 Effect of crop rotation against diverse classes of pests and diseases

ping 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 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). Also 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.

Variety of choice can be considered as an important factor in crop rotation. (Partially) resistant varieties stop or slow down the propagation rate of the harmful species. Tolerant varieties show little (economic) damage from pest and disease pressure. Cultivating resistant or tolerant varieties can be a very powerful and effective preventive tool in crop protection. However, monogenetic resistance against mobile and fast propagating pathogens often is broken quite rapidly.

Crop rotation also can play a role in the prevention of weeds. Crops differ in their capacities to cover the soil and their different speed of development. Crop diversification can help to prevent the development of weed populations adapted to a specific crop. Also the mechanical control alternatives are considered in the design of the crop rotation. In specific crops, (specific) weeds can be very efficiently controlled, which gives a cleaner starting point for the following crop. In the Manual on Prototyping Methodology and Multifunctional Crop Rotation, the design of multifunctional crop rotations (MCR) and agro-ecological layout (see next section) is discussed in more detail.

The design of an agro-ecological layout

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. This concerns not only the choice of a multifunctional crop rotation (see Manual on Prototyping Methodology and Multifunctional Crop Rotation), but also the agro-ecological identity of the farm.
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. These ensure a maximum contribution of the MCR to the prevention of pests and diseases (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 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 several methods:

- *Hedgerows and field margins:*
  Hedgerows and field margins serve as refuge sites for many animal species and increase the number of beneficial arthropods. They eliminate drifting of pesticides from or to surrounding fields or bodies of water. Plant species should be nectariferous and offer a microclimate favourable to natural predators. First, an assessed must be made that they are not an alternate host for the pest species.
- *Sown strips of weeds.*
  The presence of weed strips can increase the numbers of natural enemies near the crops. For example, the strips sown with *Galinsoga ciliata and Stellarai media* have been studied in cereals. These strips increase the number of aphid predators, such as syrphids.

Other methods of increasing bio-diversification

Bio-diversification is widely recognised as a factor of equilibrium not only in agro-ecosystems, but also in any of the environments that are found in nature. The more homogeneous they are, the more biotypes will be affected by any incidence. In farming systems, bio-diversity can be increased at different levels: the design of a crop rotation increases bio-diversity at a field level, and the design of an agro-ecological layout works at a farm level. Also different scales can be distinguished within bio-diversity. Bio-diversity refers to the number of species and the diversity within a species (for example, the genetic diversity of cultivars or subspecies). The presence of different predator and competitor species can help to bring about a balance among the potential harmful organisms in farming systems. Intercropping and mixed cropping is an agronomic alternative for breaking monocultures and increasing biodiversity, and is gaining interest in research institutions. However, up until now, these have too many technical difficulties to overcome in modern agriculture.

The natural predators hypothesis states that both generalists and specialists will be more abundant in polycultures than in monocultures. Larger numbers of polyphageous predators, such as carabids, sirfids have been found in polycultures more than in monocultures. The effect of using polycultures on specialists is less clear. There is no unequivocal proof that increasing natural predator activity causes a decrease in the density of the herbivore population. An example of intercroppping is the combination of alfalfa and cereals. Parasitic *Hymenoptera*, specifically *Ichneumonoidea*, needs water and cool temperatures and are, therefore, always collected in the alfalfa. Intercropping cabbage or leek with clover (*T. repens and T. subterraneum*) has shown good results in terms of suppression of oviposition and larval populations of various pests, although competition for nutrients, water and light reduced marketable yield.

Water management and soil structure
A good water purity and soil structure maintains the vitality and health of crops by providing optimal growing conditions for the crop. Concerning pests and diseases, these elements prevent the occurrence of specific diseases such as *Phytium spp.* and the soil biodiversity is also potentially enhanced (see also effects of biodiversity).

Cultural methods
Cultural measures involve altering the habitat to make it less favourable for pest reproduction and survival. The application of cultural methods must be based on a biological and ecological foundation, just as much as any other technique. A thorough knowledge of life history and habits of the pest is particularly essential. At the same time, an understanding of the ecosystem is necessary because habitat modification may be harmful for one pest, but could well favour one or more others. Altering plant density and plant spacing, for example, is used to control relative humidity within the crop and also the possibility of infection and propagation of diseases.

The right timing of sowing or planting dates to avoid favourable conditions for infection or periods with high disease pressure in the plant's susceptible stages can be included in a specific agronomic practice. Several examples can be given: weed control is much more difficult in summertime because of watering for farms in the Mediterranean regions; in Eastern Spain, weed control is much easier from October to February. The incidence of viruses is also dependent on the time of the year. Also in Northwestern Europe, the cabbage fly has specific periods that the different generations disperse. The first dispersals can be predicted quite accurately and planting dates can be adjusted to these flights.

Timing and method of harvesting can be manipulated as well to reduce pest populations. Strip cutting of alfalfa is a classical example. Row distance can be adapted to the available machinery and equipment. Accurate and regular rows and an even surface are an important agronomic practice to make the mechanical control of weeds easier.

Another agronomic aspect that can influence pest and disease development and damage is timing and amount of irrigation. Irrigation influences the crop microclimate and as such, it influences the development of pests and diseases. Washing the pests of the susceptible plant parts is another technique that is sometimes used.

The objective of soil tillage is to establish and preserve soil's condition. This provides optimum conditions for the cultivation and growth of crop plants, and maintains its long-term productive capacity. Soil tillage can indirectly reduce the chance of damage by creating the optimum growing conditions for the crop. However, there are also some examples of the direct action against harmful organisms. The most impressive result of soil tillage is weed control. The use of various types of soil tillage before and after crop cultivation can play a large role in the prevention of weeds during cultivation. Effects of soil tillage on pests and diseases can be the control of pests in susceptible stages (pupae or eggs) and the spreading of pests through soil tillage (see also farm hygiene). Insufficient soil tillage can create favourable conditions for a wide range of soil pathogens. For example, compacted, wet soil provides very favourable conditions for *Phytium, Phoma, Erwinia and Fusarium* species.

Nutrient management
The aim of nutrient management is providing an optimal supply of nutrients to a crop. Sub-optimal nutrient supply can cause losses because of nutrient deficiency, but also can cause a higher susceptibility to harmful species. Fertilisation levels that are too high as well as too low can cause the crop to be more susceptible to pests and diseases. Nitrogen supply can influence the microclimate within a crop, which can cause a higher risk of infection of diseases. Poorly grown plants, on the other hand, are often also more susceptible to pests and diseases. Application of organic manure can have, in addition to the increased nutrient supply, a positive effect on the anti-phytopathogenic potential of the soil. On the other hand, weed seeds can be imported with organic manure.

2.3.3 Monitoring and need of controls
Several steps could be followed to establish whether it is or not necessary to take any action to control the potentially "harmful organisms":
- determine if organisms are harmful,
- monitor,
- prognosis of infestation or infection,
- prognosis of economic loss.

Determine if organisms are harmful
First of all, it has to be determined which harmful organisms can influence normal growth or cause a decrease in

yield or quality. The set of potential harmful organisms is different for every crop, for every region and for every field in the case of weeds. This step is essential because expertise about what needs to be detected simplifies monitoring.

Monitoring

Detection of the initial infection can be site-specific or regional, depending on the pathogen. In some cases, the harmful organisms are known to be always present in small quantities (for example, *Botrytis cinerea*). In other cases, it must be detected by monitoring. Regular monitoring in vegetable crops is very important because many organisms can colonise and damage the crop very quickly. The frequency of checking and the sampling size in the field is dependent on many factors such as the stage of crop growth, the potential danger of the organisms and their development, and climatic conditions. Once or twice a week can be considered the correct frequency when the risks are high.

While monitoring, all the areas in the field must be inspected, zigzagging through the entire field and choosing plants to be sampled randomly. Usually, there are no guidelines indicating how many sample sites are needed for an effective monitoring. In each case, sampling the edges of the field is important because infestations often begin in these areas. It is important to distinguish between the different developmental stages of the harmful organism because each organism has different behaviours regarding the crop, pesticides and growing cycles. Pheromones, food and sticky traps are commonly used to detect the presence of certain pests, although they are sometimes used to determine the need for control (for example, in some cases of Lepidoptera or wireworms). The monitoring of weeds consists basically of determining their occurrence, development and their level of infestation in the field.

Prognosis of infection or infestation and economic loss

Once the pest or disease is detected in the crop, the need for control involves the prognosis of infestation or infection and development, and prognosis for potential economic loss. Before taking measures to control the organisms, it has to be established whether there is a chance for infection or infestation and whether this can cause economic loss (including the costs of control). In order to carry out this prognosis, an expert level of epidemiological knowledge about the harmful organisms is required, including symptoms, pest and disease cycles, natural enemies, ecological niches and optimal conditions for its development.

There are several factors that must be taken into account in order to predict whether the pathogen will cause economic damage or not. Examples are the levels of infestation or infection together with the stage of crop development, the number of natural enemies and the climatic conditions.
In case of diseases, their rate of development and the resulting damage are influenced by the genetic characteristics of the plant, its stage of growth when infection or stress occurs, other stresses occurring at the same time and environmental conditions, especially temperature and humidity (Flint, 1987).

When symptoms are detected, the diagnosis is usually difficult because different diseases can cause the same symptoms or the similarity between symptoms of different diseases can be minimal. Analysis in specialised laboratories is frequently required to find out the identity of a specific disease. In monitoring diseases, it is important to record the distribution of the symptoms (scattered plants, concentrated in certain areas or generally distributed). Soil and climatic conditions, as well as the humidity within the canopy should be recorded because the development of pathogens (especially initial infection) is often dependent on these microclimatic conditions.

Various monitoring systems as well as economic or treatment thresholds have been developed to establish the need for control of pests and diseases in the most important crops. However, this is not the case for a large range of pathogen-crop combinations in less important vegetable crops. The main reason is probably the relatively small area of vegetables in the whole group of crops, and the large variety of vegetable crops and their pathogens.

Thresholds for pests and diseases can be established, but in weed control, tolerance to weed seed density should in principle be set to zero. Especially when the seed bank is still rather small. For some weeds, this is, however, almost impossible in practice. Establishing species and size of the weeds is important to decide which type of control is the best to be used. For instance, doses of herbicides have to be higher when weeds are larger.

2.3.4 Physical methods of control

In physical methods of control, one should distinguish between weed control and pest and disease control. For mechanical weed control, a variety of tools are available, which have reduced the dependency on chemical control and minimise the need for manual labour.
The right choice of tools and timing are essential for the success of mechanical control. No general recommendations can be given for mechanical weed control. The strategies are very much dependant on soil, crop and climatic conditions. There are various alternatives for mechanical control of weeds between the rows. Control of weeds within the rows, especially in sown crops with fine seeds (onion, carrots), however, is still problematic. Sometimes, physical control of weeds is not possible because of weather conditions, which makes an addition-

al treatment of chemical control or manual weeding necessary. Proper seedbed preparation is also important for successful mechanical weed control. It may be necessary to adapt planting or seeding distances to the available mechanical tools.

False seedbed technique is another physical alternative for mechanical weed control. It consists basically of preplant ploughings and seedbed preparation, preceded by irrigation (or profiting from rain) that causes the germination of weed seeds. This technique will help to lower the weed seed bank of the field, however, it must be repeated as often as possible for an optimal result.

Mulching is also considered as another physical method for weed control. Covering the soil with polythene (in combination with fertigation) is a standard practice in the cultivation of crops, mainly in the Mediterranean countries. The advantages and disadvantages of this must be evaluated for every crop.

The alternatives for physical control of pests and diseases are limited. In some cases, identification and removal of infested plants can be successful. For soilborn diseases, techniques such as steaming, inundation, anaerobic decomposition of organic matter (bio-fumigation) or solarisation can be successful. It is important to point out that the last two techniques should be applied only in extreme cases, when no other solution is available because these can potentially have the same effect as chemical soil disinfections by causing disequilibrium in the biota of soils.
Physical barriers are used to stop the harmful organisms from reaching the crop or crop parts where they can do damage. There is a wide range of possible physical barriers, often very specific for individual pathogen-crop combinations. The advantages (effective control, environment) and disadvantages (costs, labour, agronomy) need to be thoroughly considered. A few types of physical barriers are quite commonly used. Insect nets, for example, can be used as protection against pests, as well as against diseases (often viruses) that these insects can transmit. Again the agronomic advantages have to be weighed against costs, possible extra labour and agronomic disadvantages such as problematic weed control and susceptibility against diseases (higher humidity in the crop).

2.3.5 Biological control

Classical Biological Control can be defined as the regulation of the population of a harmful organism's density using natural enemies to a lower rate than would otherwise occur naturally. This definition implies that man's activity manipulates the environment to favour of the presence and activity of natural enemies. Biological control could be divided into three different types: use of entomopathogen micro-organisms, use of antagonist micro-organisms and use of entomophagus (Ripollés, 1986).

The use of fungus, bacteria or virus (enthomopathogen micro-organisms can cause an epidemic in the organism that needs to be controlled. Formulations of viruses are only occasionally used for the control of pests in vegetable crops. The most important and most used bioinsecticide is the bacteria ***Bacillus thuringiensis*** against several species of *Lepidoptera and L. decemlineata.* Because ***Bacillus thuringiensis*** is formulated with toxic crystals included in the bacteria, it is questionable whether it should be considered as a biological or a chemical control, because the organisms do not reproduce in the field. The fungus *Beauveria bassiana* is used mainly for the control of white flies in some vegetable crops.

The use of antagonists for the control of diseases is still in an early stage, although it is expected that its use will be increased in the coming years. These antagonist organisms usually are fungi or bacteria that do not damage the crop, but eliminate or restrain the development of the disease. As examples, the bacteria *Streptomyces* sp. is used for the control of *Fusarium sp.* and the fungus *Trichoderma spp.* are active on *Acremoniun, Fusarium, Rhizoctonia and Sclerotinia,* in addition to others.

Entomophagus insects can be used in two ways: the introduction of exotic natural enemies and the addition of parasites and predators. It must be stated that, in addition to these two practices, the best option will always be to promote conservation or the enhancement of the autochthonous natural enemies (see Chapter 2.3.2, Prevention).

- *The introduction of exotic natural enemies:* This should be done very carefully and only with those known to be specific. Unfortunately, this is usually not the case in vegetable crops. For instance, aphid parasites are generalists as well as leaf miner parasites. Exotic white flies are controlled by native parasites too. The only exception is in sweet corn: *Ostrinia Trichogramma.*
- *Augmentation of parasites and predators:* This augmentation to increase their effectiveness involves their direct manipulation either by mass releases or periodic colonisation. Species of the egg parasite *Trichogramma* have been utilised more than any other entomophagous enemies for inoculative or inundative releases have been utilised. Currently, this modality is being used in greenhouses and infrequently in field-grown vegetable crops.

Regarding the inundative releases, the efficiency of predaceous coccinelids in natural or managed systems is difficult to determine given their mobility and their polyphagous nature. The role of naturally occurring *Coccinelidae* in suppressing pest populations is significant, but poorly documented. The insects are generally released as adults in augmentation programs, but non-target effects have not been examined. The concentration of large number of coccinelids in augmentative releases is likely to increase cannibalism.

2.3.6 Chemical control

In an IECP strategy, pesticides are used only when there is no another feasible alternative to control the dangerous organism. If pesticides are chosen, then two main aspects have to be taken into consideration: effectiveness in controlling the target organism(s) and their effects on the environment (emissions and damage). The chosen pesticide has to be effective against the harmful organism(s) that have to be controlled. Aspects such as selectivity, resistance of the harmful organism(s), weather conditions (temperature, humidity) and the developmental stage of the crop and target species have to taken into account. Within the range of effective, acceptable pesticides, a choice can be made for the most environmentally safe pesticide. The physical properties of the pesticide play an important role in this choice.
For the proper use of pesticides, it is necessary to follow the directions on the label, giving special attention to dosage, dangers to users, harvest intervals, toxicity for man, wildlife, and natural predators, authorised crops and possible phytotoxicities, and expiry dates. Their working capacity should be optimised and, at the same time, their use minimised, preventing the pesticide emission and undesirable side effects as much as possible.

Selectivity

Obviously, the choice of a pesticide will first depend on how well it works in controlling the target harmful organism. This can be improved for pests and diseases with the selectivity of a pesticide because this property helps to maintain the equilibrium between natural enemies and pests or between antagonist and pathogen micro-organisms. The selectivity of a pesticide can be physiological or ecological. The first one is a characteristic inherent to the active ingredient and the second one depends on its use, that is to say, on the timing, dose, application technique, type of formulation, and persistence (Ripollés, 1986). In herbicides, the selectivity will be necessary not only with regard to the growing crop, but also to the following crops if residues of herbicides remain.
Pest resurgence and/or secondary pest outbreaks
Therefore, the effects of selected pesticides on the different natural enemies should be very well known to avoid pest resurgence and/or secondary pest outbreaks. Pest resurgence occurs when pesticide destroys the natural enemies of a target pest. Because the natural enemies depend on the pest for food, they take much longer than the pest to build up to their former numbers. Meanwhile, the pests that survive the treatments breed without being restrained by natural enemies, sometimes building up to a greater number than existed before the treatment (Flint, 1990). The secondary pest outbreak happens when certain species usually do not reach critical numbers due to the action of natural enemies. If these natural enemies are removed by a treatment, the secondary species is released from their pressure and may reach damaging numbers. It is very common with spider mites, but it can happen also with weeds when herbicides allow a few tolerant species to survive. When the competing weeds are removed, the tolerant species grows easier. Also, colonisation with soil-born diseases in disinfected soils is much easier than in well-balanced soils.

Resistance to pesticides

Pesticides' efficiency will increase if the resistance of harmful organisms to pesticides is eliminated as much as possible. Therefore, it is necessary to alternate the applications with different active ingredients. If possible, these active ingredients should belong to different classes. Resistance develops more quickly under the selective pressure of repeated pesticide application. In addition, lower doses than recommended are in some cases the reason certain resistances develop. On the other hand, developing cross-resistance to several pesticides is not rare, even though they belong to different chemical groups. Resistance has been reported in aphids, spider mites, worms, leaf miners and several other diseases.

Pesticide choice and reducing emissions and damage

In addition to minimising the use of pesticides and optimising their efficacy, there are other techniques to reduce the emissions and damage of pesticides. The choice of pesticide according to its different levels of emissions to air, groundwater or soil is very effective if this can reduce the effect on the environment, as it has been demonstrated in the different VEGINECO systems (see Chapters 3-6).

To quantify the emissions in the (a-biotic) environment independently, PPO developed a concept called Environment Exposure to Pesticides (EEP). EEP is quantified 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. Emissions are calculated for the routes to the air, groundwater and soil (see Annex 5).

This concept fits into the strategy of integrated farming systems. In the development of these systems, the use of this property aims at minimising any potential effect of pesticides on flora and fauna. Therefore, the exposure of the environment to pesticides (EEP) should be minimised. This can be accomplished by minimising the farming systems' pesticide requirements (Integrated Crop Protection). Consequently, the pesticides are carefully selected while taking into account the extent to which the environment is exposed to pesticides. If more than one pesticide is available to control an organism, the pesticide with the lowest emissions is chosen. Emissions to the air are considered as the most important route that needs to be reduced, emissions to the soil the least important route. Therefore, a pesticide with a low risk of emissions to the air and high risk of emissions to the soil is preferred above a pesticide with high risk of emissions to the air and low risk of emissions to the soil.

Each year, a list should be made of the highest scoring pesticides for each emissions route, then solutions should be sought to prevent the use of these pesticides either by being replaced with another pesticide or by changing the crop protection strategy. In this way, total emissions from pesticides can be reduced from year to year.

Pesticides damage the crop and to other non-target organisms in and out of the fields. Damage can be caused by the use of obsolete pesticides, excessive dosage, incompatible mixes, inadequate climatic conditions or an incorrect application technique. Damage to the crop can also be caused by the lack of crop tolerance. With herbicide applications, the crop can sometimes be protected from damage by the use of screens or caps next to the nozzles. Using hedges or zones that are not sprayed can reduce damage to non-target organisms outside the field. In addition, neighbouring crops can be protected with these steps as well. Wearing appropriate protective clothing and cabins on tractors can prevent damage to farm worker's health. Respecting the legally set interval between the last application and harvest can prevent damage to consumers.

In organic farming, natural pesticides are used. These 'organic' pesticides can also have the same effects as synthetic pesticides on environment, biota and human health. Therefore, the use of "bio-compounds" such as ***azadiractin*** or ***rotenone***, and mineral compounds such as copper or sulphur will be absolutely considered as chemical controls in organic farming. Because of this, organic farmers in the Netherlands hardly use any 'organic' pesticides at all. In the Dutch organic system, no pesticides are used at all (see Chapter 3).

Optimising efficacy and minimising use

After choosing the right pesticide, an optimal combination between its efficacy and effectiveness on the environment, and its application can be optimised. Again both efficacy and effectiveness on the environment have to be taken into account. Aspects such as timing, dosage and application technique also play an important role

Timing

Timing is an important factor to improve the efficacy of pesticides. In the case of pests, it is necessary to know the cycle of the different pests and their natural enemies, as well as the crop characteristics to determine the best time to spray (when the pest is most vulnerable). In this way, fewer applications are needed and the efficacy of applications can be improved. On the other hand, herbicides are applied more efficiently in a lower amount per hectare in low dose systems (LDS). With these systems, herbicides are applied in a very early growing stage of the weeds and with lower doses than conventionally used. This low dose treatment should be repeated if the effect of first treatment was not good enough. The advantages of LDS system are:

- weed species are more vulnerable in a young growth stage (even strengthened by repeated applications),
- applications are less selective at a young growth stage,
- the degree of weed control increases,
- the accumulative amount used to control weeds is often substantially lower than the conventional high dose approach,
- crop damage is lower because of lower doses (lower phytotoxicity).

Naturally this technique demands sophisticated sprayers. On the other hand, climatic conditions are most important to determine the best timing of treatments. Wind, for example, may considerably reduce the efficacy and increase the emissions of pesticides.

Application techniques

Different application techniques influence the efficacy of pesticides and reduction of use. With a hand sprayer or more conventional techniques, larger quantities of water are usually necessary (higher than 400 l ha^{-1}). For large-scale farming, the use of these large quantities of water is more time consuming and costly, and therefore, medium to low volume techniques have been developed. At the same time, these techniques have enabled much more accurate and uniform dosing and a better adaptation of the application technique to the specific pest, crop and pesticide (pressure, droplet size, types of nozzles). However, these technically improved machines are often not suited or economically not feasible for small-scale vegetable farming. In some cases, pests or weeds can be sprayed through spot-wise application because of their limited distribution, and therefore a smaller amount of pesticide is applied. In these cases, the application must be done manually. In each case, the machinery must always be well calibrated for the correct distribution of the pesticide.

Pesticide doses

The use of the proper pesticide dose is another way to minimise its use and optimise its efficacy. There are different methods to determine the pesticide dose. One can find two types of advice on the label:

- concentration of the application solution (and also the solution amount) or
- amount of product per surface unit.

The first type of advice is usually used in situations when the dosage is not (only) dependent on surface area, but also on crop size such as tomatoes or green beans, for example. Another situation, where a fixed concentration is used, is if an exact dosage per ha is difficult to achieve (small-scale applications, spot-wise applications). In these cases, the dose depends on the amount of spray liquid that is applied.

The second type of advice is more predominant in crops with a closed canopy and two- dimensional crops, arable crops and many open field vegetable crops. The last type of advice has become predominant in the Netherlands because of the improved technical possibilities to apply an exact dosage. In this case, a fixed amount of water per ha is used. In theory, both methods have to lead to the same used amount for the same crop-disease combination. In practice, the first method tends to give more variations in use.

Mixtures of pesticides with bioactive foliar feeds or urea sometimes allow doses of systemic pesticides to be lowered. In the same way, the mixtures of contact and feed pesticides with mineral oil are used to reinforce the effect and persistence of pesticides, allowing also for a reduction of the pesticide dose.

Other factors

Other factors that influence pesticides are weather conditions, physical properties of pesticides, soil characteristics for herbicides and the characteristics of the crops. In general, there are interactions between these factors that influence the pesticides' efficacy. The following are several examples of interactions between pesticide properties and these factors:

- The a-polar compounds are generally less weather dependent.
- Transport and uptake in gaseous form is very dependent on temperature.
- Systemic pesticides have to be taken up by the plant and this process is weather and plant dependent.
- Non-systemic pesticides in general need finer dispersion than systemic pesticides. A finer dispersion can mean more water and/or a smaller droplet size.
- Soil herbicides are very much influenced by soil (surface conditions (humid-dry), and rainfall.

The interaction between pesticide properties and weather conditions is quite important. Applied Plant Research, DLV and Opticrop in the Netherlands have linked both together in a computer program called (GEWIS) developed. The program uses weather conditions and forecasts inside and outside the crop to predict how well an application of a certain pesticide will work. This program provides an extra tool to support decisions in pesticide choice and timing of the application. For some pesticides, it also gives advice about pesticide dose.

2.3.7 Testing and Improving

After crop protection strategies have been designed, they need to be tested in practice. The layout of the prototype requires that the model be tested and improved until the objectives have been reached. Because this stage is the most labour intensive and expensive step, at least a full rotation of the prototype on each field (4-6 years) is required; it is useful to take a critical inventory of all the methods previously designed before developing a new prototype (Vereijken, 1999). It is important to check the compatibility of the crop protection strategy with the other methods used. This can be done by estimating the parameters that are used to test and improve the model. The parameters that can be used to evaluate I/ECP can be divided in three groups. The first group of parameters is greatly influenced by I/ECP. The second group of parameters is partially influenced by I/ECP. However, other methods are important as well to the parameter values. The third group is slightly influenced by I/ECP. In Table 2.1, the major objectives that are quantified by I/ECP related parameters are shown. A short description of the parameters can be found in Annex 2. In the manual on prototyping methodology and multifunctional crop rotation (Chapter 4), the reason why these parameters were chosen is explained.

Parameters can only be used to test and improve farming systems if target values are established. In Chapter 4, the justification for parameters and target values is discussed. In addition, the EEP parameters are prioritised. The parameter, EEP air, is considered the most important, followed by EEP groundwater and EEP soil.

The crop protection strategy is evaluated by calculating the amount of pesticides used and the environmental effects of the pesticides. When target values are not reached, changes in the strategies need to be made. Therefore, it is necessary to determine the problematic combinations of pesticide, crop and pest, disease or weed. First, the five most important pesticides that contribute to the total parameter values are determined for each pesticide exceeding the target value. Secondly, a list can be made with the pesticides, which need to be replaced first. Finally, replacement or reduction in use needs to be considered. If possible, pesticides in the list should be replaced by preventive measures. If preventive measures are insufficient, more environmentally friendly pesticides should be chosen. If no alternative pesticides are available, reducing use should be considered either by establishing the need for control or the use of different application techniques, which require reduced use (low dose systems, row sprayings or spot wise applications).

An example of this testing and improving strategy is given in Figure 2.3. The figure depicts the improvement in the EEP air in the Integrated Fresh Market system (Italy, I INT2). Large reductions were already achieved in the first year compared to previous years, and in the following years, the results continued to improve. The main improvements were:

- the substitution of Butisan for Ramrod (resulting in a lower EEP groundwater as well) and the use of mechanical weed control (ridging),
- fewer treatments with Hostaquik (better choice of

Table 2.1 I/ECP related themes and parameters

	Abbreviation	Theme
Parameters greatly influenced by I/ECP		
Pesticides input active ingredients, Environment Exposure to Pesticides Hours Hand weeding	PESTAS, EEP soil, air, groundwater HHW	Clean Environment Clean Environment Farm continuity
Parameters partially influenced by I/ECP		
Quantity of produce, Quality of produce Net Surplus	QNP, QLP NS	Quality production Farm continuity

treatment time),
- Sumisclex was replaced by Scala.

Of course, the choice of the pesticides was based on the other emission parameters as well.

Another important parameter, which is greatly influenced by IECP, is hours of hand (manual) weeding. Input of hours for manual weeding can be an important cost factor and should be minimised from an economic point of view. Evaluation parameters, partially influenced by IECP, are quantity and quality of the yield and the economic result of the farm.

In the following chapters on the individual countries, some examples are given of the application of the theoretical design of integrated or ecological crop protection strategies in different countries. The difficulties, problems and particularities of each country are stressed. Some significant results are given, however, thorough results are included in the VEGINECO Final Report. Some background information about the systems can be found in Annex 1.
Crop protection strategies are usually crop and pathogen-specific although aspects at a farm level, for example, cropping plan, rotation and farm hygiene play an important role. The strategies deal with crop specific and harmful species, weeds, diseases and pests for each group. The stable strategies are the result of four years of testing and improving. In the testing period, many techniques that did not lead to stable and reliable methods were tested. These methods are not dealt with in this chapter, but are explained in Chapter 7.

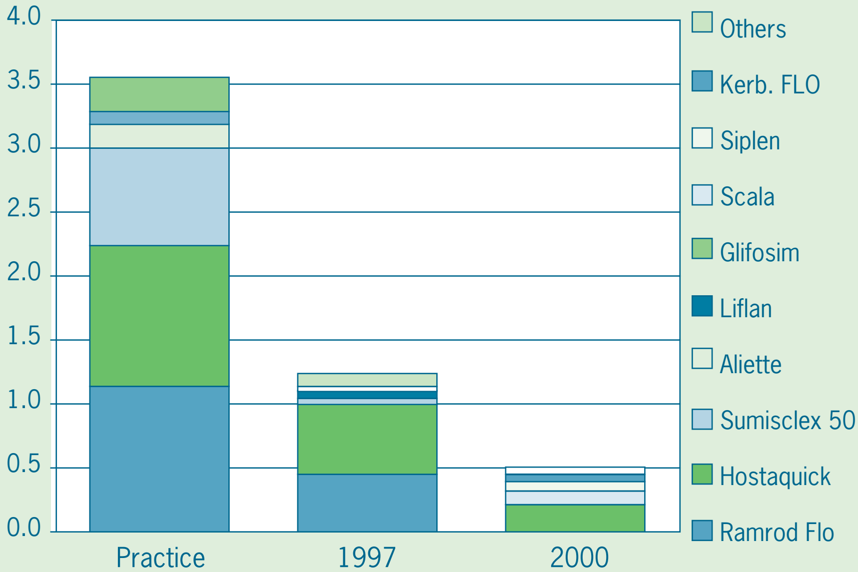

Figure 2.3 Example of the reduction in EEP air in the Integrated Fresh Market system (Italy, I INT2). The figure depicts the contribution of different pesticides for average practice from the first year of the project and the final year of the project. The reduction is about 70%.

3 A practical case of crop protection strategies in the Southwest of the Netherlands

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3.1 Introduction

The Dutch integrated vegetable farming systems are located in Westmaas, which is in the South-western clay region of the Netherlands. Approximately 18% of the Dutch field-grown vegetable surface area (7 466 ha in 1996) is located in this region. The main vegetable crops in this region are onions, chicory, winter carrots, Brussels sprouts, and celeriac. The amount of iceberg lettuce and various other vegetable crops such as fennel, cauliflower and broccoli being grown is smaller, but increasing rapidly. The main types of farms are the specialised vegetable farms (mainly Brussels sprouts) and arable farms with vegetable crops. Specifically in Southwest region, but also nation-wide, there is a growing tendency to include vegetable crops in arable rotations. This is accomplished by either by specialised farms leasing land from arable farms or by arable or organic farmers growing vegetable crops. This tendency could also be benefit the existing intensive vegetable rotations. The research on the integrated and organic systems variations in Westmaas tries to answer the specific sustainability issues that are a result of this development.

Two types of integrated extensive vegetable systems and one organic extensive vegetable system were tested at one location. The choice of crops in both systems was based on the region and soil. For both systems, the same main crops were planted.

The basis for proper crop protection in the integrated systems in Westmaas is a four-year arable rotation, in comparison to six year long rotation in the organic system. In the integrated systems, cereals and potatoes are the arable crops and either Brussels sprouts or iceberg lettuce is the main vegetable crop. The second vegetable crop is either celeriac, fennel or cauliflower. This set up led to seven system variations for the two cropping plans for the main vegetable crops, which covers the range of cultivation types (from early (spring) to late (autumn) cultivations) within the vegetable crops (Table 3.1, see Manual on Prototyping Methodology and Multifunctional Crop Rotation for more details).

3.2 Weed control strategies

3.2.1 General weed control strategy

General

The strategies for weed control are aimed at minimising the number of hours of manual weeding. Manual labour for weeding is expensive and available labour is limited. The specific situation at the experimental farm influenced the possibilities for weed control and had to be taken into account. Weed pressure is quite low and strategies were aimed at maintaining this situation. The soil type is middle-heavy and crust-forming clay. This determined whether or not the soil could be worked after wet periods and the type of mechanical weed control tools that can be used. Weed control machinery has to work quite aggressively on this soil to be able to remove the weeds.

Prevention

The strategy starts with the design of the crop rotation. Whenever possible, aspects of weed control were taken into consideration. The following effects were used in the design of the crop rotation:

- Planted vegetable crops (preferably a brassica) after potatoes because it is easier to control potential potato volunteers.
- A cereal crop helps to eliminate volunteer weeds and provides a clean start for the next crop.

Another important prevention strategy was to make a clean start for the crop cultivation. Aspects of this strategy are:

- Preventing weed seeds from establishing themselves in the crop and in the field margins as much as possible. Actually most manual weeding hours are not used to prevent the risk of competition and yield loss, but to prevent weed seeds from getting established.

Table 3.1 General scheme of the two integrated rotation types in NL

	NL INT 1 (Brussels sprouts) (4 variations)	**NL INT2 (Iceberg lettuce)** (3 variations)
1	potatoes	potatoes
2	**Brussels sprouts**	fennel/celeriac/cauliflower
3	winter wheat/spring barley	winter wheat/spring barley
4	fennel/celeriac/iceberg lettuce	**iceberg lettuce**

- The main soil cultivation technique is ploughing, which gives a much cleaner start than mixing soil cultivations.
- Mechanical control, just before cultivation. Whenever possible and necessary, weeds are controlled before crop cultivation in order to make a clean start. One of the options used is the false seedbed technique.

Control aspects

If control in a crop is needed, various means of mechanical and physical control are first utilised. Of course, control costs also play a role in this choice. Only when mechanical control is considered insufficient or mechanical control results in too many hours of manual weeding, chemical control will be used. In some cases, herbicides are used for emergency applications, for example, if weather circumstances have been extreme and this made mechanical control impossible. If possible, mechanical control is utilised in a very early stage of weed development. This requires regular and close inspection of weed germination and development.

If chemical control is used, herbicides with low emission risks will be chosen also taking into consideration, of course, the efficacy of the herbicide in controlling the weed population. Furthermore, chemical control is utilised at an early stage of weed development, which makes it possible to lower the dose of the herbicide and use low dose techniques.

3.2.2 Weed control strategies for each crop

Table 3.2 is an overview of the available machinery for physical weed control, Table 3.3 represents a summary of the weed control strategies.

Brussels sprouts and cauliflower

Brussels sprouts (integrated and organic) and cauliflower (integrated) are crops in which weeds can be controlled by fully mechanical methods. Due to the crops' quick development, two or three treatments (harrowing, hoeing, hoeing and ridging) are sufficient. Before the late planting period of Brussels sprouts, pre-planting treatments can control many types of weeds. In the integrated systems, this is only possible in very wet periods with chance of structural damage. This pre-cultivation control was done with ***glyphosate***.

Celeriac

Celeriac (integrated) is planted late and a weed-free start is important. The weeds before planting were removed with a few mechanical treatments (in emergencies with ***glyphosate***). Celeriac is a crop that stays open until the end of the growing period so a long control period is necessary. Two strategies were tested: completely mechanical (harrowing and ridging hoe) or a combination of mechanical and chemical. The second strategy included mechanical applications of harrow and hoe in the row combined with a LDS row application (0.25 kg ha^{-1} ***linuron*** + 0.25 kg ha^{-1} Agral; Agral is an adjuvant).

Table 3.2 Overview of available machinery in the integrated and organic system in the Netherlands

Machine	Type	Width m	Row spacing m	Crops
Inter row cultivator for nursery tractor	Hoe	1.50	0.50, 0.32, 0.26	fennel, celeriac, iceberg lettuce, barley, wheat
Inter row cultivator in front of tractor	Hoe (with ridging strips)	3.00	0.75 0.50	cauliflower, Brussels sprouts, celeriac
Mini harrow behind each hoe	Harrow	1.50 3.00	0.50, 0.75	cauliflower, Brussels sprouts, celeriac
Soil crumbling cultivators (pre seedbed operations, two types)	Cultivator with crumbling roles	3.00		all crops
Ridging rotary cultivator	Cultivator	3.00		potatoes
Flexible chain harrow	Harrow	3.00		potatoes
Angle blade with ridging (covered)	Hoe and ridger	3.00	0.75	potatoes
Spring tine harrow	Harrow	6.00		Brussels sprouts, fennel, celeriac, cauliflower, wheat, barley
Weed flamer	Weed flamer	1.50		pre-emergence (contractor)

Table 3.3 Overview of weed control strategies per crop, integrated and organic system, number indicates number of treatments unless otherwise indicated

Crop	System	Row distance m	Harrow	Hoe	Ridged hoe	Spray application[1]	Herbicide type[2]	Low dose technique	Expected additional manual labour[3]
		Mechanical control				Chemical control			
Brussels sprouts	Int. + Org.	0.75	0-1	1	1-2	–	–	–	1
Cauliflower	Int.	0.75	–	1-2	–	–	–	–	1
Celeriac 1	Int.	0.50	–	3	–	–	C/S	X	2
Celeriac 2	Int.	0.50	2	4	–	–	–	–	2
Fennel planting (cover)	Int.	0.50	–	-	–	FF	C/S	–	1
Fennel sowing	Int.	0.50	–	1	–	FF	C/S	X	2
Fennel planted	Int. + Org.	0.50	–	1	–	–	–	–	2
Iceberg lettuce	Int. + Org.	0.32	–	x	–	–[4]	–	–	2
Potatoes	Int. + Org.	0.75	1	x	–	–[4]	–	–	1
Winter wheat	Int.	0.13	3	–	–	FF	C	X	1
Spring barley	Int.	0.13	2	–	–	FF	C	X	1
Spring wheat	Org.	0.26	1	1	–	–	–	–	1

1. FF = full field, R = row or band spray, SP = spot-wise
2. C = contact herbicide, S = soil herbicide
3. additional manual labour needed: 1 = < 20 hours ha^{-1}, 2 = 20-40, 3 = 40-60, 4 = 60-80, etc.
4. standard no chemical application except in emergency cases in integrated

Fennel

In the planted fennel (integrated and organic) hoeing between the rows provided good control. Because of the long growth period, 3-4 treatments were necessary. Remaining weeds in the row have to be removed by hand. For the late planting period, a pre-planting treatment can control many types of weeds. Experimentally, the use of the harrow was tested.

In the early covered (fleece) fennel (integrated), the use of mechanical weed control was limited because of the extra labour and plant damage due to removing the fleece during the treatment. Therefore in this cultivation type, a chemical spray of 1 kg ha^{-1} ***linuron*** shortly after planting was used.

For the sown fennel (integrated), a basic row application was not enough. Because of this, a full field application of 0.5 kg ha^{-1} ***linuron*** was used. This application made the soil weed-free in the first four weeks. Next, a Low Dose System (LDS; 0.25 kg ha^{-1} ***linuron*** + 0.5 kg ha^{-1} Agral LN) was used in combination with hoe treatments between the rows. Before the late sowing period, a pre-planting cultivation controlled a large amount of weeds.

Iceberg lettuce

Weeds were controlled mechanically in iceberg lettuce (integrated and organic) crops. The first hoe treatment had to be carried out 7-10 days after planting. Usually two treatments were necessary. Extra attention had to be paid to weeds in the row. Only in the early covered crop of iceberg lettuce (integrated), the use of 4 l ha^{-1} ***chlorpropham*** due to weed pressure or unfavourable conditions was used as an emergency application.

Potatoes

In potatoes (integrated and organic), late weed control was completely done by building ridges in combination with hoe. In the integrated system, a chemical application of Titus was used when conditions were very unfavourable for mechanical control.

Winter wheat and spring barley

In winter wheat and spring barley, hoeing was the main mechanical treatment. In the integrated system, only if black-bindweed, chamonile and cleavers were insufficiently controlled, then a low dose chemical application of ***metsulfuron*** + ***fluroxypyr*** was applied.

3.3 Disease and pest control strategies

3.3.1 General disease and pest control strategies

General
Pests and diseases can cause very high or complete yield and quality losses in vegetable crops much more than in arable crops. Small defects on the product can make the product unmarketable. These high quality requirements play an important role in the necessity of controlling pests and diseases. Moreover, yield losses also mean large financial losses because investments in seeds, plants and labour are high. A stable strategy and delivering a marketable product is the most important limiting condition for the pest and disease control strategies developed.

Prevention
The strategy starts with the design of the crop rotation. Whenever possible, aspects of disease control are already taken into consideration in the crop choice and rotation. The following issues were used in the design of the crop rotation:

- Crop choice. The rotation is composed, as much as possible, of crops from different plant families. Also in the choice of catch crops, this principle has been taken into account. When genetically related species are used, cultivation in succeeding years is avoided.
- Field adjacency. If it is possible, it is preferable to avoid planting crops on fields adjacent to the fields where they were planted the previous year.
- Enhancement and preservation of natural predators: Attention is paid to the development of an ecological infrastructure on the farm in which the choice for a species that provides food and shelter for natural predators plays a role. Moreover, if possible, selective pesticides are used in order protect natural predators.
- Choice of variety. If possible, varieties are used which are resistant or tolerant against the main pests and diseases. Even if yield or quality aspects are lower than non-resistant varieties. In the organic system, these choices are more important than in the integrated systems.
- Plant material or seeds. In order to make a clean start, plants and seeds have to be healthy and free of infection. Plant material is visually controlled before planting. Good and reliable suppliers or producers of plants and seeds are important (quality guarantees).

Farm hygiene is another important strategy in the prevention of pests and diseases. Important aspects are the quick incorporation of crop residues after cultivation and cleaning of machinery. In fertilisation, the crop protection aspect is also considered. Abundant crop growth as well as irregular crop growth due to fertilisation is avoided. In some cases, physical barriers such as insect nets are used to protect the crop from harmful species.

Need for control
Before methods of control are applied, the need for control has to be established. Whenever available and manageable, warning systems, damage thresholds and guided control systems are used. Regular crop inspection and weather forecasts are necessary instruments in establishing the need for control.

Control aspects
When control in a crop is needed, first the possibilities of physical or biological control are utilised. Of course, control costs also play a role in this choice. Some antagonist and natural predators have been applied on an experimental basis (see Chapter 7), but these strategies are for several reasons (efficacy, stability and costs) not yet included in a standard strategy. 'Organic pesticides' such as ***azadiractin***, pyrethroids or ***Bacillus thuringiensis*** are not applied in the organic system.

The residual problems in the integrated systems are controlled with pesticides. For chemical control, pesticides with low emission risks are chosen. Of course, the efficacy of the pesticide in controlling the disease or plague is taken into consideration. The most optimal physical (weather) conditions for application are used to increase the application's effectiveness and/or to be able to lower the advised dosage. Every crop-pesticide-pathogen combination has its own optimal application conditions. Weather forecasts within and outside the region are essential for these considerations.

3.3.2 Disease control strategies for each crop

The crop-specific protection in the organic systems is the same for the non-chemical part as for the integrated systems unless otherwise indicated. However, in organic farming, the focus on this non-chemical crop protection is more important and higher costs for non-chemical protection are acceptable. The strategies presented are for the most important diseases, all of which can cause considerable damage. Strategies are summarised in Table 3.4.

Brussels sprouts
For Brussels sprouts, the basis for control of *Mycosphaerella brassicicola, Albugo candida, Erysiphe cruciferarum* and *Alternaria brassicae/brassicicola* is prevention through choice of variety. Differences in varieties of resistance to these diseases are present, however, not always very well known.
Especially for *Mycosphaerella*, crop residues are worked into the ground directly after harvest because spores can be easily dispersed from old infected leaves. A guided control system is available for *Mycosphaerella*. With the aid of a thermo-hygrograph, the infectious periods are examined. Chemicals are applied for *Mycosphaerella* only after appearance of the first spots and only when the conditions for infection are favourable. The product used

Table 3.4 Overview of the most important disease control strategy per crop

		Prevention					Need for control				Chemical control in integrated systems			
Crop	Disease	Crop rotation[1]	N-Ferti-lisation[2]	Seeds/plants[3]	Variety choice[4]	Incorporation/removal of residues[5]	Signal[6]	Damage threshold[7]	Guided control[8]	Physical control	Seed plant treatment[9]	Preventive or curative	Fulfield/row/spot[10]	Low dose[11]
Brussels sprouts	*Mycosphaerella brassicicola*	X	-	-	X	XX	XX	-	XX		-	P/C	FF	XX
	Albugo candida	X	XX	-	XX	X	XX	-	-		-	P/C	FF	X
	Alternaria brassicicola	X	-	-	X	X	XX	-	-		-	-	-	-
	Erisyphe cruciferarum	X	-	-	XX	X	XX	-	-		-	-	-	-
Cauliflower	*Mycosphaerella brassicicola*	X	-	-	X	XX	XX	-	-		-	-	-	-
Celeriac	*Septoria apiicola*	X	X	X	X	X	XX	-	X		-	P/C	FF	-
Iceberg lettuce	*Bremia lactucae*	-	-	-	XX	X	-	-	-		(X)	(P)	(FF)	(X)
	Bottom-rot complex	XX	-	-	-	X	-	-	-		-	-		-
Potato	*Phytophthora infestans*	-	X	X	XX	XX	-	-	-	B[12]	-	P	FF	XX
Barley	Divers airborne diseases	-	X	-	XX	-	XX	XX	XX		-	C	FF	XX
Wheat	Divers airborne diseases	-	X	-	XX	-	XX	XX	XX		-	C	FF	XX

All chemical control only applied in the integrated systems
XX = very effective or very frequent
X = limited effective and/or manageable
\- = not relevant or not possible

1. Is crop rotation effective as a preventive measure?
2. Is nitrogen limitation effective as a preventive measure?
3. Is infestation control or selection of seeds and plants effective?
4. Are there resistant or tolerant varieties available and used?
5. Is quick removal or incorporation of residues of the crop used?
6. Does control only takes place after detection of the disease and is this effective?
7. Is a damage threshold used?
8. Are there any guided control systems used?
9. Is planting or seed treatment used?
10. Are pesticides applied in the field: FF = full field, R = row or band application, SP = spot-wise?
11. Is the applied dosage lower than that advised on the package?
12. B = Burner

for treatment is the curative and preventive pesticide ***pyrifenox***. ***Pyrifenox*** provides also partial control for powdery mildew and *Alternaria*. There are no benzimidazoles used because of their toxicity for the environment. For the prevention of *Albugo candida*, a steady and controlled growth is essential. A chemical application ***(chlorothalonil)*** is used when occurrence and weather conditions are expected to lead to yield or quality losses. No damage thresholds or guided control systems are available. *Erysiphe cruciferarum* is usually not a problem with the use of tolerant and resistant varieties. Only if there is high chance of disease and/or a severe infection, is *Erysiphe* chemically controlled with ***pyrifenox*** (if possible together with control of *Mycosphaerella*). *Alternaria* is only controlled chemically ***(iprodione)*** when there is a very high chance of disease and an infection in the crop.

Cauliflower
In cauliflower, fungal diseases cause fewer problems than in Brussels sprouts. However, in autumn plantings, *Mycosphaerella* can cause a severe infection. The control system is the same as for Brussels sprouts. A higher incidence for fungal diseases can be tolerated because there is almost no damage to the product. In the four years of testing, no chemical control against diseases was utilised.

Celeriac
In celeriac, *Septoria apiicola* is a large problem. First, partial resistant and tolerant varieties are chosen. In addition, a thermo-hygrograph is used to establish leaf-wet duration and predict the infectious periods. There is no curative chemical available, therefore, as soon as the first spots are detected, the disease is chemically controlled. There is a preference for ***chlorothalonil*** above ***carbendazim*** because of its reduced effect on the environment. A guided control system for *Septoria apiicola* is being developed.

Fennel
In fennel there are, due to a wide rotation, hardly any problems with fungi. There is no chemical control needed.

Iceberg lettuce
In iceberg lettuce, the fungi that cause bottom rot-complex *(Sclerotinia, Pythium spp., Rhizoctonia)* and *Bremia lactucae* are the main problems.
In the four-year rotation, smut was not a problem, so there was no need for a preventive chemical control. Bremia lactucae was not a problem as long as resistant varieties were available. However, this resistance was broken occasionally. Without resistant varieties, one treatment with ***fosethyl-aluminium*** was used on the plant material. Two weeks after planting, a treatment with ***fosethyl-aluminium*** was used in the field. However, this strategy does not always lead to a completely marketable product.

Potatoes
In the potatoes, the starting point in the control of late blight is the variety of choice. In the organic system, an early variety was chosen. In this strategy, the crop can partially escape from the highly infectious periods. When local infection was found, these spots were burned with the weed burner. After the infection exceeded a certain threshold, the full crop was burned to prevent the crop being a source of infection for the region. In the integrated system, an intermediate resistant for market reasons was chosen in combination with preventive chemical control with ***fluazinam***. Depending on the weather, 6 to 12 applications were necessary. Under dry weather and crop conditions, a low dosage of ***fluazinam*** was used.

Cereals
In cereals, tolerant or resistant varieties were chosen. Abundant crop development was avoided with a moderate fertilisation. Moreover, a guided control with damage thresholds was used. On average, two applications against diverse diseases in wheat and barley were necessary.

3.3.3 Pest control strategies per crop

The non-chemical strategies for organic and integrated production are similar if not otherwise indicated. Nematodes are not mentioned in the strategies. Nematodes are regularly monitored and no problems are expected. The strategies are summarised in Table 3.5.

Brussels sprouts
For integrated Brussels sprouts, caterpillars and aphids are successfully controlled with the help of guided control and damage thresholds. However, damage thresholds for *Plutella xylostella* and *Brevicorne brassicae* still need some adjustments.
The control of *Contarinia nasturtii* is based on registration of the insects' flights together with the use of a weather model. This method, however, still needs some improvement.
The first generation of the *Delia brassicae* is completely controlled by seed coating. At the moment, there is no valid method available for targeted control of the next generations. The chemical control is combined with applications for aphids and caterpillars.
For chemical control of caterpillars, ***deltamethrin*** and ***acephate*** are preferred, and for the control of aphids, the insecticides ***pirimicarb***, ***oxydemeton-methyl*** and ***thiometon*** are preferred.
Slugs can cause a lot of damage. Much attention is given to prevention before cultivation (control of weeds, soil cultivation). If necessary, the slugs can be controlled by ***metaldehyde*** or ***methiocarb***.
For organic Brussels sprouts, slugs and larvae of *Plutella xylostella* lead to very high quality losses. Stable and economically viable strategies are still not available. Therefore, focus has been on tests and improvements of several options. Focus on the control of *Plutella xylostella* and other insects have been on covering the crop with insect nets. To control slugs, focus has been on rotation, creating unfavourable conditions for survival and biological control with nematodes and predators. The results of testing various methods are given in Section 3.1.3.

Cauliflower
For integrated cauliflower, damage caused by insects is much lower than in Brussels sprouts. Cabbage fly, caterpillars, aphids and cabbage gall midge are controlled in the same way as in Brussels sprouts, however, damage thresholds are generally higher.

Celeriac
In celeriac, insects are not much of a problem. With help of close monitoring (visual and sticky traps), insects can be easily controlled with a limited amount of insecticides. The insecticides ***pirimicarb***, ***heptenophos*** and ***mevinphos*** are preferred. ***Propoxur*** is only used when ***mevin-***

Table 3.5 Overview of the most pest control strategies per crop

		Prevention				Need for control			Chemical control in integrated systems		
Crop	Disease	Crop rotation[1]	Selection seeds/plants[3]	Variety choice[4]	Crop cover[5]	Signal[6]	Damage threshold[7]	Guided control[8]	Seed/plant treatment[9]	Fulfield/row/spot[10]	Low dose[11]
Brussels sprouts	*Delia brassicae*	X	–	–	X (org.)	–	–	XX	XX	–	
	Plutella xylostella	–	–	–	X (org.)	X	X	–	–	FF	X
	Slugs	X	–	–	–	XX	–	–	–	FF	X
	Brevicorne brassicae	X	–	X	X (org.)	X	X	X	–	FF	X
Cauliflower	*Delia brassicae*	X	–	–	–	–	–	–	XX	–	–
	Noctuids, caterpillars	–	–	–	–	XX	XX	XX	–	FF	X
	Brevicorne brassicae	X	–	–	–	XX	XX	X	–	FF	X
Celeriac	Aphids	X	–	–	–	XX	–	X	–	FF	X
	Lygys-sp	X	–	–	–	X	–		–	FF	X
Fennel	Aphids	–	–	–	–	XX	–		–	FF	X
Iceberg lettuce	Aphids	–	–	XX	–	XX	–	–	–	FF	X
	Noctuids, caterpillars	XX	–	–	–	XX	–	–	–	FF	x
Potato	Aphids	–	–	–	–	XX	XX	–	–	FF	X
Barley	Aphids	–	–	–	–	XX	XX	XX	–	FF	X
Wheat	Aphids	–	–	–	–	XX	XX	XX	–	FF	X

All chemical control only applied in the integrated systems

XX = very effective or very frequent

X = limited effective and/or manageable

\- = not relevant or not possible

1. Is crop rotation effective as a preventive measure?
2. Is nitrogen limitation effective as a preventive measure?
3. Is infestation control or selection of seeds or plant effective?
4. Are there resistant or tolerant varieties available and used?
5. Is quick removal or incorporation of residues of the crop used?
6. Does control only takes place after detection of the disease and is this effective?
7. Is a damage threshold used?
8. Are there any guided control systems used?
9. Is planting or seed treatment used?
10. Are pesticides applied in the field: FF = full field, R = row or band application, SP = spotwise?
11. Is the applied dosage lower than advice on package?

phos is not effective enough against Lygys species. Flights of the carrot fly have been monitored, but control has not been necessary yet.

Fennel

In fennel, insects are not much of a problem. Aphids can cause a problem in a young growth stage of the crop. In this period, extra attention needs to be paid to monitoring aphids. With the help of damage thresholds, the aphids can be easily controlled. *Thrips tabacii* can cause some quality damage and is therefore regularly monitored. Chemical control of thrips has not been necessary yet.

Iceberg lettuce

In the cultivation of iceberg lettuce, the control of aphids has been much improved by the availability of *Nasonovia ribisnigri* resistant varieties. In both the organic and the integrated systems, these resistant varieties are used. With the use of resistant varieties and damage thresh-

Table 3.6 Pest and disease causes of shortfall in quality production

System	Crop	Quality reduced by	Disease/pest cause	Shortfall in strategy
NL INT1	Brussels sprouts	QLP, spots and coloration on product	*Mycosphaerella, Alternaria,* diverse Fungi	Control timing and frequency
NL INT1	Iceberg	QNP, Insufficient development,	*Bremia lactucae*	Control frequency,
NL INT2	lettuce	loss of plants QLP, coloration or lesions on product		choice of fungicide Availability of resistant variety
NL ORG	Potato	QNP, Loss leaf area	*Phytophthora*	No efficient control available
NL ORG	Brussels sprouts	Insects feeding damaged product	Slugs	Green manure, preceding clover, humid soil conditions
NL ORG	Brussels sprouts	Insects feeding damaged product	*Plutella xylostella*	Insufficient cover, insect nets
NL ORG	Iceberg lettuce	QNP Insufficient development, loss of plants QLP coloration or lesions on product	*Bremia lactucae*	Availability of resistant variety

olds, chemical control is applied in one or two applications usually with ***pirimicarb*** or ***dimethoate***. The choice of the insecticide is dependant on the aphid species and the necessity to alternate insecticides. The use of seed coating is not yet allowed, however promising for the future. Caterpillars can be a problem, but can be easily controlled with the use of damage thresholds. Most of the time chemical control is not necessary.

Potatoes
In potatoes, insects are not much of a problem. With the help of damage thresholds, the insects can easily be controlled.

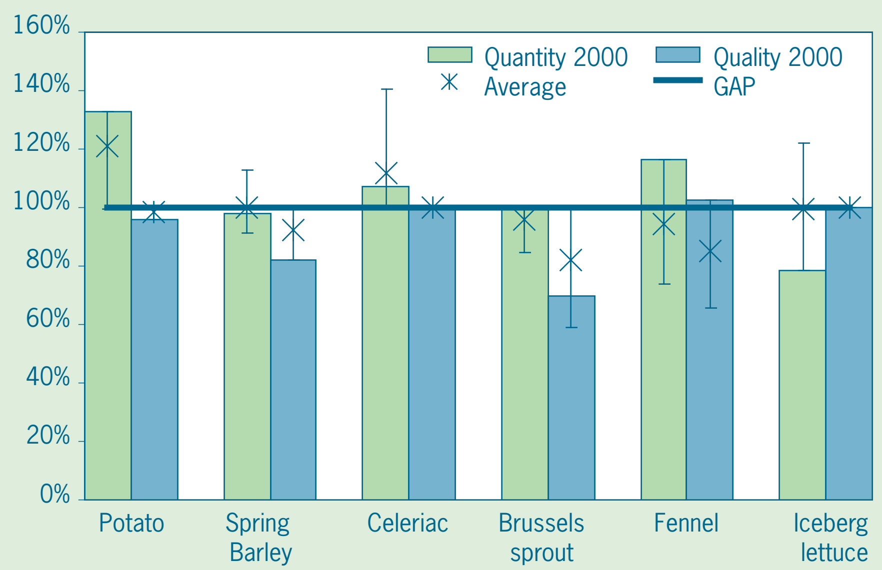

Figure 3.1 Level of quality per crop compared to GAP production (100%) in NL INT1

Cereals
In cereals, aphids can be controlled easily. With help of damage thresholds and guided control, insects can easily be controlled.

3.4 Testing and improving

3.4.1 Control strategies, quality production costs and manual weeding

Quality production can be greatly affected if disease control strategies are insufficient to control harmful species. The quality production achieved (Figures 3.1 to 3.3) is compared with the defined levels according to conventional Good Agricultural Practice.

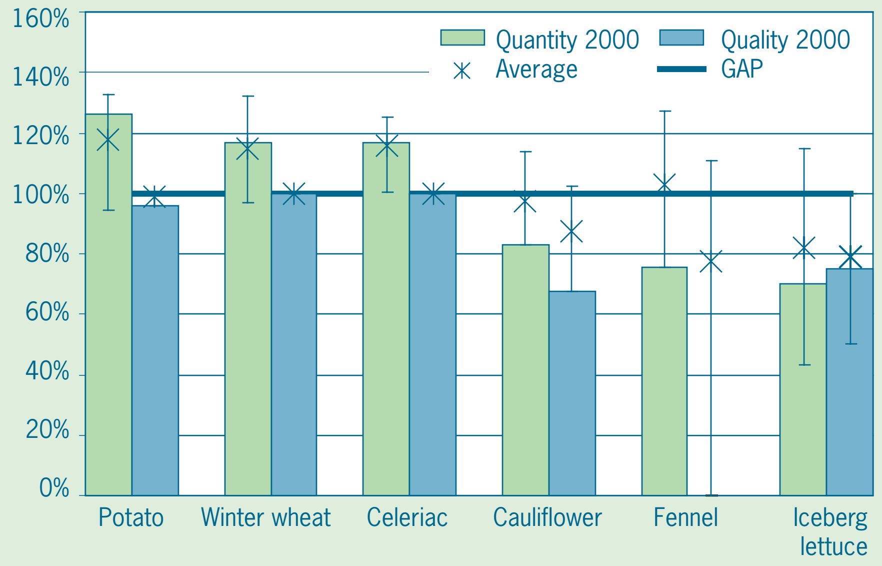

Figure 3.2 Level of quality per crop compared to GAP production (100%) in NL INT2

The level of quality production in average conventional practice normally achieved is about 90% of GAP. The level achieved in the system compared with the level achieved in average practice is, however, difficult. For organic production, there is large difference in quality production compared to conventional GAP. Therefore, the level of quality production achieved is also compared with a target specific for organic production.
The deficit in level of quality production caused by pests and diseases in the integrated system was mainly found in iceberg lettuce and Brussels sprouts (Table 3.6). For organic production, this was the case for Brussels sprouts, iceberg lettuce and potatoes. The deficit in the other crops was caused either by the fertilisation strategy or by unfavourable weather conditions.

In the integrated Brussels sprouts, the quality loss was mainly caused by spots and coloration on the product, which are usually caused by a complex of fungi. Brussels sprouts are a very vulnerable product and only very slight damage during sprout development can cause severe quality damage. Varieties that are more resistant were not available, but would help a great deal. The exact timing (weather conditions, damage thresholds) of chemical control measures still has to be improved to prevent damage. As a last option, the control frequency could be increased. In the integrated iceberg lettuce, quality and quantity loss was partly caused by unfavourable weather conditions. In practice, quality production is variable for this reason too. Another cause is the reduction of resistance against downy mildew in 1999. Especially under humid conditions (autumn cultivations), the strategy of two applications of ***fosethyl-aluminium*** could not completely prevent loss in quality production. However, in practice even with an intensive chemical control, quality losses due to downy mildew do regularly occur.

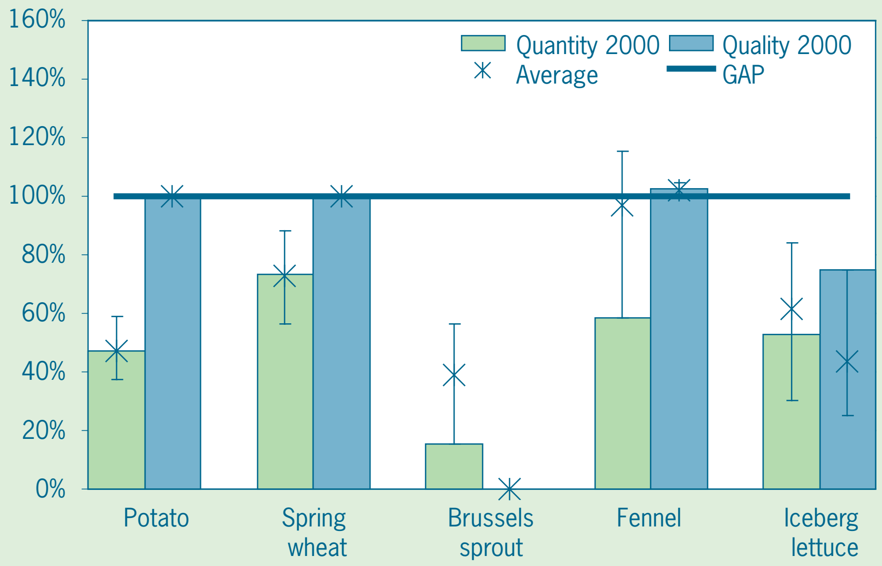

Figure 3.3 Level of quality per crop compared to GAP production (100%) in NL ORG

In the organic system, the quality of the produce is judged against conventional quality requirements for class 1. However, in practice, quality class 2 is very often marketable and receives a good price. Brussels sprouts is the most problematic crop regarding quality production. Both pests and diseases cause reduction in quality production. The main problems are slugs and the back diamond moth. Insect nets were able to prevent most damage caused by the back diamond moth, but this strategy is still not completely safe. Moreover, the use

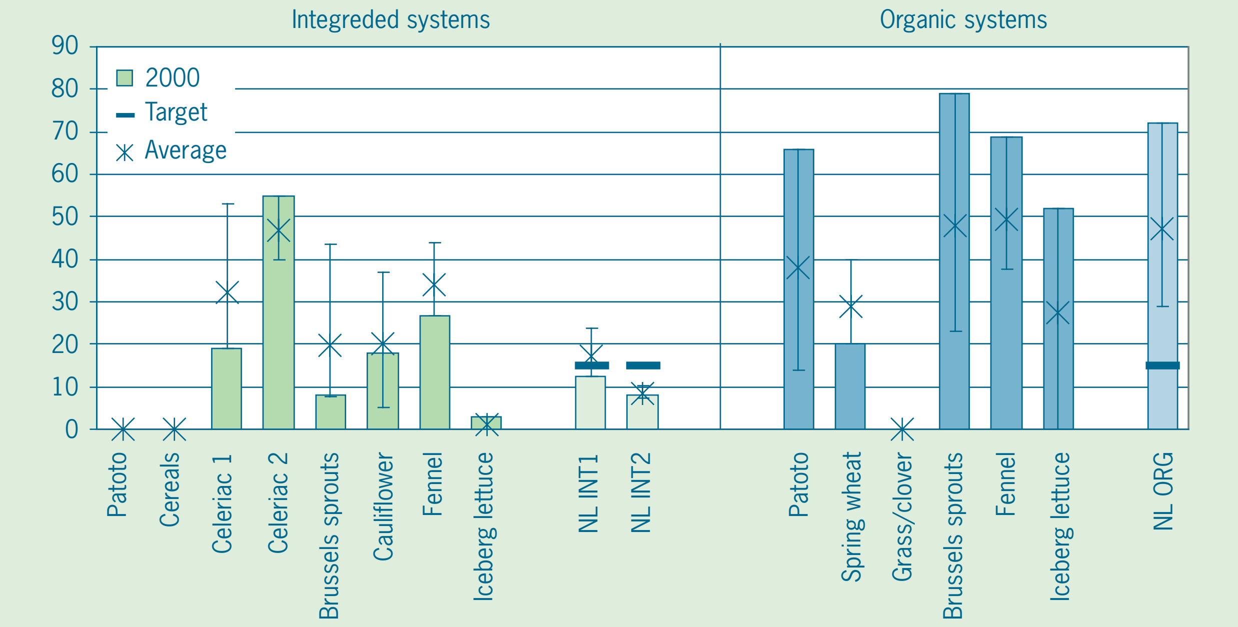

Figure 3.4 Hours of manual weeding per crop (hours ha^{-1})

of insect nets is quite labour intensive, costly, hinders weed control and causes humid conditions in the crop. This last effect can lead to the faster development of diseases.

Also the control strategy for slugs in the organic system was not sufficient. Development of a sufficient strategy is still ongoing. Different strategies for slug prevention were also tested such as changes in the preceding crop and green manure use. In addition, different slug control measures were tried such as the use of ducks and nematodes. The experiments did not yet lead to a sufficient strategy.

In iceberg lettuce in the organic system, the deficit in quality production was partly caused by insufficient nitrogen availability. Another reason for this deficit was the reduction in resistance against downy mildew. The control of aphids in iceberg lettuce with a Nasonovia resistant variety was very successful.

There were no negative effects on quality production identified for the weed control strategy. Another parameter for quantifying the success of the weed control strategy is the amount of labour needed for hand weeding (HHW). In the integrated system (Figure 3.4), HHW in vegetable crops was restricted to one or two times of walking through the crop and removing some remaining weeds. The combination of chemical and mechanical weed control in celeriac 1 proved to be more effective than the complete mechanical control in celeriac 2.

In the organic system, hours of manual weeding were higher than in the integrated system. However, the results are comparable with estimations for the average organic practice. The results of 2000 were negatively influenced by unfavourable weather conditions in most cases, as HHW in 2000 was the highest for the four years of testing. This was partially caused by the previous use of organic parcels that resulted in the appearance of thistles and *Raphanus*. The problems with the biannual thistle increased throughout the period.
Moreover, the success of mechanical weed control on clay soil is very dependent on the weather conditions, which causes a large variation in the results from different years. Other causes of the differences between the organic and integrated systems are the sometimes slow or irregular development of the canopy (potato, lettuce and Brussels sprouts) and, of course, the use of herbicides (fennel). Diverse alternative strategies, for example the use of the finger weeder, have been tested, but have not been found stable enough.

3.4.2 Pesticide use, emission and damage risks

In the organic system, no 'organic' pesticides such as copper, sulphur or ***Bacillus thuringiensis*** were used. In Dutch practice, the use of bio pesticides is very low as well.
In the integrated systems, the applied strategies strongly reduced use, emission and damage risks of pesticides compared to average practice (Table 3.7). The pesticide input for average practice was based on the registration of a group of conventional farmers. This group of farmers can be classified as environmentally conscientious and are as such not expected to perform worse than average practice. In the region, many fields border waterways, which present the risk of pesticides emissions to

Table 3.7 Realisation of parameters related to pesticide use and emission

	number of applications no ha^{-1}	pesticide input kg ha^{-1}	EEP air kg ha^{-1}	EEP groundwater ppb	EEP soil kg days ha^{-1}	EYP surface water no. appl. > 10
NL INT1						
Conventional 2000	21.8	11.9	1.5	6.23	801	13.4
Actual 1997	12.9	3.3	0.6	5.98	250	10.1
Actual 2000	10.1	2.5	0.7	0.01	167	6.1
VEGINECO target	-	5.9	0.5	0.50	240	0
% reduction 2000 - conventional	54	79	57	99.9	79	54
NL INT2						
Conventional 2000	19.0	8.1	1.4	8.01	479	9.3
Actual 1997	9.8	2.6	0.7	7.96	217	6.2
Actual 2000	8.2	2.3	0.4	0.01	156	3.9
VEGINECO target	-	4.0	0.4	0.5	144	0
% reduction 2000 - conventional	57	72	69	99.9	67	58

Table 3.8 Main differences in herbicide inputs between conventional and realisation in VEGINECO 2000

Crop	Application type	Conventional pesticide	Pesticide 2000	Difference in strategy
Potato	Full field in crop	***metribuzin*+ *prosulfocarb***	-	Complete mechanical control
Potato	Defoliation	***diquat***	-	Mechanical defoliation
Fennel		***glyphosate***	-	Mechanical pre-crop control
Fennel	Full field in crop	***linuron***	***linuron***	Lowe Dose System with ***linuron***
Brussels sprouts	Full field in crop	***metazachlor***	-	Lowe Dose System with ***linuron***
Brussels sprouts	Pre-planting control	***glyphosate***	-	Mechanical pre-planting control
Celeriac	Full field in crop	***linuron***	***linuron***	Low Dose System
Iceberg lettuce	Pre-planting control	***chlorpropham***	-	Complete mechanical control

water life and this is used as a local parameter. The risk to water life is called Environmental Yardstick Points for Water life (EYP wl). EYP wl expresses whether a pesticide application is a risk that can lead to damage of water life. The minimum value of 10 points for a specific application corresponds with the concentration level of a pesticide that has no effect. All applications with an EYP wl > 10 exceed the accepted level of risk for water life. EYP wl is dependant on the choice of pesticide, application technique and buffer zone between waterway and crop.
The main reduction was found in the input of fungicides and of herbicides. The a.i. input in the integrated system in 2000 was minimal (0.07 – 0.18 kg ha^{-1}) for herbicides. Fungicides caused the highest input of 3.0 kg ha^{-1} for NL INT1 and 2.2 kg ha^{-1} in NL INT2.
The reduction in pesticide use did not lead in all cases to a comparable reduction of emission and risk of damage.
The reduction of EEP groundwater was large because the differences between pesticides in their capacity to leach were large. Using the option to replace leachable pesticides, EEP groundwater was reduced by almost 100%.

Different aspects of the applied strategy (Tables 3.8 to 3.10) caused the reductions in emission and use. Important elements in the reduction of use and emissions were close observation, damage thresholds, choice of pesticide, lower doses and the use of non-chemical control methods. The effect of preventive measures on pesticide input reductions are difficult to assess. However, prevention is an integral element in the integrated control strategies.
For weed control (Table 3.8), the main reduction in use and emission was achieved by the replacement of chemical control by mechanical control and the use of low

Table 3.9 Main differences in fungicide inputs between conventional and realisation in VEGINECO 2000

Crop	Disease	Conventional fungicide	Fungicide 2000	Difference in strategy
Potato	Late blight	***fluazinam*** ***cymoxanil+ mancozeb***	***fluazinam*** -	Lower dosages Replaced by preventive strategy with fluazinam
Potato	Late blight	***chlorothalonil+ propamocarb-hydrochloride***	-	
Brussels sprouts	Ring spot	Dorado ***carbendazim***	***pyrifenox*** -	Lower doses Strategy with pyrifenox is sufficient
Brussels sprouts	White blister	***chlorothalonil***	***chlorothalonil***	Lower frequency
Brussels sprouts	*Alternaria*	***iprodione***	-	Close observation, no application necessary
Celeriac	*Septoria*	***maneb fentin acetate*** ***chlorothalonil***	- ***chlorothalonil***	Strategy with only ***chlorothalonil*** Lower frequency

dosage systems applied in a very early weed development stage.
For disease control, most of the reduction in use and emission comes from lower frequencies and lower dosages usually based on close observation of disease infection and development. In the case of white blister in Brussels sprouts and *Septoria* in celeriac, the less preferable ***chlorothalonil*** is still used in the VEGINECO strategy. However, now there are no better alternatives. This item also relates to another growing problem in vegetable crops, which is the availability of allowed pesticides in the relatively small vegetable crops. For some crops, there are no more pesticides available for the control of specific harmful organisms or the allowed pesticides that are left over lead to higher inputs and emissions. For example: there will be no insecticide left in celeriac, ***chlorothalonil*** will also be banned as fungicide against *Septoria* in celeriac, the rather soft fungicide ***pyrifenox*** will be withdrawn which will lead to the use of environmentally less favourable compounds such as ***benomyl*** and ***carbendazim***.
For insect control (Table 3.10), the most important causes of reduction in use and emission are choice of pesticide, lower frequency and to a smaller extent a lower dosage. The lower frequency is based on close observations, damage thresholds, guided control and optimising efficacy. Lower dosage and/or optimisation of efficacy is mainly achieved by choosing the right pesticide for the right weather conditions.

Table 3.10 Main differences in insecticide inputs between conventional and realisation in VEGINECO 2000

Crop	Pest	Conventional pesticide	Pesticide 2000	Difference in strategy (2000)
Potato	Divers aphids	***dimethoate*** ***lambda-cyhalothrin*** ***deltamethrin***	-	Close observation, no application necessary in 2000
Fennel	Divers aphids	***deltamethrin*** ***pirimicarb***	***(pirimicarb)***	Damage thresholds, only occasional input in sown fennel in early stage; no application necessary in 2000
Brussels sprouts	Back diamond moth, *Brevicoryne brassicae* Other insects	***lambda-cyhalothrin*** ***pirimicarb*** ***acephate*** ***dimethoate*** ***heptenophos*** ***deltamethrin***	***acephate*** ***deltamethrin*** ***thiometon*** ***pirimicarb***	Selection of pesticides with reduced emissions; choice of pesticide dependant on temperature; lower frequency of applications. Applications are usually for a combination of insects with focus on back diamond moth and Brevicoryne. In VEGINECO, back diamond moth is signalled with pheromone traps
Brussels sprouts	Slugs	***metaldehyde*** ***methiocarb*** ***aldicarb***	***methiocarb***	Choice of pesticides with reduced emissions; close observation leads to lower frequency and lower dose.
Celeriac	Aphids Lygys species	***mevinphos*** ***pirimicarb***	-	No control, because of future withdrawal of allowed pesticides
Iceberg lettuce	Aphids	***dimethoate*** ***pirimicarb*** ***heptenophos***	***dimethoate*** ***pirimicarb***	Lower frequency, starting point is *Nasonovia* resistant variety.
Iceberg lettuce	Diverse caterpillars	***deltamethrin***	***deltamethrin***	Lower frequency

4 A practical case of crop protection strategies in Emilia-Romagna (Italy)

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4.1 Introduction

In Italy, three farming systems were developed, two integrated systems and one organic. All systems were located in the eastern part of Emilia-Romagna (ER) on loam and clay soils. In ER, about 55 000 hectares of field-grown vegetables were cultivated with the main vegetable crops were tomatoes for industrial processing, potatoes, onions, melons, and field-grown vegetables for the frozen food industry. In the eastern part of the region, the most important crops are strawberries, lettuce, celery, fennel (fresh market) and green beans (fresh market and industry). There are three main types of field-grown vegetable farms: specialised farms growing vegetables for the fresh market (2-3 ha), farms growing vegetables for industry and arable crops (15-20 ha), and farms growing vegetables for the fresh market and arable crops (8-10 ha). During the past few years, integrated and organic products have become more important on the market. For this reason, the project has been used to verify and improve the application of these farm practices for field-grown vegetable farms.

Three rotations, two aimed at fresh market crops (I INT2 and I ORG) and one at the combination of arable crops and field-grown vegetables for industry (I INT1), were tested. The choice of crops in the three systems was based on the importance of different crops for the market and on the suitability for the local agronomic conditions.

The rotation of the organic system (I ORG) was designed analogous to I INT2; with the only difference being that fennel was grown instead of celery. The organic rotation was changed at the end of the first year because the nutrient management strategy resulted in large surpluses. Cauliflower and spring lettuce were removed from the rotation. The crop rotations are shown in Table 4.1.

In this chapter, the resulting stable strategies for pest, disease and weed control after four years of testing and improving are reported. Tested strategies that did not yet lead to stable and reliable crop protection are presented in Chapter 7, discussion and conclusions.

4.2 Weed control strategies

4.2.1 General weed control strategies

General
The most important objective in weed control was the reduction of pesticide input in the integrated systems and successful weed control in the organic system with an acceptable amount of manual weeding hours.
The weed control strategy was designed taking into account farm organisation, soil type and weed pressure. A limitation in the design of the weed control strategy was the lack of efficient small-scale mechanisation to control weeds.

Prevention
Weed control was not a primary aspect that influenced the choice of crop rotation in the same was as farm management and the economic result did. However, the rotation influenced the weed development, the number of species (avoided weed specialisation) and weed presence. Principally, this is due to the cultivation necessary for the preparation of the seedbed for the crops in succession on the same field. A rotary hoe was used to reduce weed development, especially rhizome weeds.

Control
In the organic system, the strategy was aimed at a lower input of manual labour and preventing loss of quality production. Therefore, maximum use was made of mechanical and physical methods. In the integrated systems, chemical weed control was substituted by mechanical control when possible (for example, spiked chain harrow in wheat). In some cases, mechanical weed control (for example, star harrow in green beans and ridging in cauliflower) has been combined with chemical control. In some crops, exclusive chemical weed control was used, as alternative techniques were not efficient or economically viable. The lack of specific machines for field-grown vegetables and not optimal soil conditions for mechanical weed control (in general clay soils) limits the possibilities for mechanical weed control. Heavy clay soils do not

Table 4.1 General scheme of the organic and integrated rotation types in Italy

	I INT1	I INT2	I ORG
1	spinach - tomato	lettuce summer and autumn - catch crop	green beans - fennel
2	wheat - green beans	green beans - strawberry	melon - catch crop
3	sugar beet	celery - catch crop - melon	strawberry
4	catch crop - melon	cauliflower- lettuce spring	lettuce summer and autumn

Table 4.2 Overview of available machinery, Italy

Machine	Type	Width m	Row spacing m	Crops
I INT1				
Rotary cultivator	Hoe	0.8	2.10-2.50	Melon and tomato
Multi-row hoe mounted on tractor	Hoe	0.3		Sugar beet, green beans
Spiked chain harrowing	Harrow	5		Wheat
I INT2				
Rotary cultivator	Hoe	0.3-0.8		All except cauliflower
Multi-row hoe mounted on tractor	Hoe	0.3		Green beans
Ridger	Ridger	0.4		Cauliflower
I ORG				
Rotary cultivator	Hoe	0.3-0.7	All	All crops
Two-wheeled tractor with toolbar attachment	Hoe	0.2-0.5	All	All crops
Weed flamer	Flamer	1.5		Lettuce, green beans and melon
Manual flamer	Flamer	0.4	0.45	Strawberry

always permit the execution of timely operations (high content of water in the soil and risk of damaging soil structure). The pesticide input has been reduced by the application of micro doses or spot-wise treatments, while environmental risks are reduced by a better choice of pesticides.

4.2.2 Weed control strategies per crop

Table 4.2 is an overview of the available machinery for physical weed control; Table 4.3 represents a summary of the weed control strategies.

Organic system

Lettuce

In lettuce, a weed-free start is important. A rotary hoe (miller) is used before planting for seedbed preparation. In the first year, a rotary hoe (rotary cultivator) was used one or two times in all cycles together with manual weeding. In the following years, the cultivator with toolbar attachment was used once during the summer cycle, while a burner was used just before planting of the autumn cycle because of low weed pressure. If necessary, manual weeding was done. Lettuce has a short growing cycle (35 days in summer and 50 days in autumn) and this inhibits the growth of weeds. This is very important for the following crops.

Green beans

In green beans, a rotary hoe (miller) was used for seedbed preparation. In the last two years, a burner was used just before emergence. The timing of the cultivation was established by a careful evaluation of seed sprouting using the window method. In the first two years, a rotary hoe (one application with the rotary cultivator) and manual weeding were used. In the last two years, a rotary hoe was substituted by with another type of hoe (cultivator with toolbar attachment) once. Sometimes it was necessary to do extra manual weeding before the harvest to eliminate the weeds that could be an obstruction for the harvest machines. The adoption of the burner and the hoe reduced the number of manual labour hours, except in the last year as a consequence of high weed pressure shortly before harvest.

Strawberry

In strawberry, black mulching was used on two-thirds of the field. Normally, the weeds near the plant are pulled out by hand when farmers clean the strawberry plants during the winter. A rotary hoe (rotary cultivator) controls the weeds between the mulches. In the last period, a hoe was substituted for the rotary hoe with better control of *Portulaca*. This weed could be controlled as well using a burner between the mulches. A rotary hoe did not control the weeds in a strip of soil (10 cm) near the mulch and for this reason manual weeding was necessary. Fifteen days before harvest, straw was put on the soil to protect the fruits from splashing mud and to control the development of weeds.

Fennel

In fennel, a weed-free start is important: for this reason a rotary hoe (miller) was used for seedbed preparation. Weed control was done by using a cultivator in the first growth phases. The rotary cultivator was used when it was not possible to use a hoe. When fennel was completely developed, weed problems were limited.

Melon
In melon, grey mulch cover was used on half of the field. The weeds between the mulches were controlled with rotary hoe. When the melon plants grew over the edges of the mulch, mechanical control was not possible so manual weeding was done. In the last two years, burning was used before mulching.

Integrated systems

Lettuce
In lettuce, a harrow was used just before planting. In order to control weeds and to reduce costs of manual weeding in the spring and summer cycles, it was necessary to spray with ***propyzamide*** (3 l ha^{-1}). In the summer and autumn cycles, it was possible to control the weeds mechanically with a rotary hoe (rotary cultivator). When necessary, manual weeding in the rows was done as well. Lettuce has a short growing cycle (45 days in spring, 35 days in summer and 50 days in autumn), but the crop was frequently irrigated. Therefore, weed control during the cultivation was necessary.

Green beans
In green beans, a weed-free start is important. A harrow was used just before planting. In I INT2, it was necessary to control *amarantus retroflexus* and *poligonum aviculare* by ***trifluralin*** + ***linuron*** (2 kg ha^{-1}). After the beans emerged, weed control was done with the multi-row hoe or the rotary cultivator, depending on the soil conditions (humidity). Sometimes extra manual weeding was necessary.
The most important weeds in I INT1 are *amarantus retroflexus* and *chenopodium album*. These weeds were controlled with ***trifluralin*** + ***linuron*** (2 kg ha^{-1}). After the beans emerged, mechanical control with a multi-row hoe was done in the first two years. In the last two years, a star harrow was used.

Strawberry
In strawberry, black mulching was used on two-thirds of the field. Normally the weeds near the plant must be removed by hand when the strawberry plants are cleaned in the winter period. Rotary hoe (rotary cultivator) controlled the weeds between the mulches. Fifteen days before harvest, straw was put on the soil to protect the fruits from splashing mud and to control the development of weeds. A rotary hoe does not control the weeds in a strip of soil (10 cm) near the mulch. These strips were cleaned manually.

Celery
In celery, a weed-free start is important. A harrow was used just before transplanting. After planting, a chemical control with ***linuron*** was used. Mechanical control of weeds is partially possible with a rotary hoe (rotary cultivator), but nevertheless manual weeding was still necessary in the rows.

Melon
In melon, grey mulch cover was used on half of the field. The weeds between the mulches were controlled with a rotary hoe (1 or 2 times) using the rotary cultivator. When the melon plants grew over the edges of the mulch, mechanical control was not possible anymore and manual weeding was necessary once or twice.

Cauliflower
In cauliflower, mechanical control was possible in the first developmental stage. Dependent on the number of weeds after transplanting, a treatment with ***metazachlor*** (1.5 kg ha^{-1}) was applied. In the following developmental stages, weeds were controlled by ridging, which aimed to support the cauliflower plants as well. When the plants were completely developed, weed problems were limited.

Spinach
In spinach, no weeds in the harvested product are acceptable to the processing industry. Therefore, a weed-free start is important. A harrow was used to prepare an optimal seedbed. A chemical application with ***lenacil*** + ***cycloate*** (0.7 + 3.5 kg ha^{-1}) was used before emergence. If necessary, one application of ***sethoxydim*** (0.5 kg ha^{-1}) for gramineaceae was used.

Tomato
In planted tomato, it was possible to use a partially mechanical control. A weed-free start is important and, therefore, a harrow was used shortly before planting. A rotary hoe was used two times between the rows while in the rows the crop was treated with ***metribuzin*** (0.5 kg ha^{-1}) or ***rimsulfuron***. If there was *solanum nigrum*, the only possible control was to use a row application of ***pendimethalin*** (2 kg ha^{-1}) before planting. If the tomato plants were fully developed, it was not possible to use mechanical control. If weed pressure from graminaceae was high, it was necessary to use ***propaquizafop*** (0.6 kg ha^{-1}).

Wheat
Weed control in wheat is carried out mechanically. Depending on weather conditions, one to three spiked chain harrow treatments were carried out.

Sugar beet
In sugar beet, a weed-free start is important. During sowing, the crop was treated in the rows with ***metamitron***. Later on, the chemical application was done with one micro dosage of ***metamitron***, ***ethofumesate*** and ***fenmedifan***. When the plants had 4-6 leafs, weed control was done with a multi-row hoe.

Table 4.3 Overview of weed control strategies per crop

	Mechanical or physical control								Chemical control			
Crop	Row distance m	Hoe no	Rotary hoe no	Flame no	Harrow no	Ridging no	Soil cover	Manual labour hours	Type of application[1]	Herbicide type [2]	Low dose technique	Manual labour hours
I ORG												
Lettuce sum	0.36	1						24				
Lettuce aut	0.36			1				0				
Melon	2.15		2	1			X	18				
Strawberry	0.85-0.35	2		1			X	123				
Green beans	0.45	1		1				116				
Fennel	0.60	1	1					162				
I INT1												
Melon	2.25		1-2				X					93
Tomato	1.50		2						R	C-S	X	85
Sugar beet	0.45		1						R-FF	C-S	X	4.4
Green beans	0.45		1						FF	C-S		2
Spinach	0.18								FF	S		4
Wheat	0.18				1-3							
I INT2												
Lettuce spr	0.37								FF	C-S		3
Lettuce sum	0.37		1						FF	C-S		28
Lettuce aut	0.37		1									2
Green beans	0.45		1						FF	C-S		8
Celery	0.37		1						FF	C-S		39
Melon	1.90		1-2				X					21
Strawberry	0.85-0.35		2				X					54
Cauliflower	0.75					1			FF	C		6

1. FF = full field, R = row or band spray, SP = spot-wise
2. C = contact herbicide, S = soil herbicide

4.3 Disease and pest control strategies

4.3.1 General disease and pest control strategies

General
In Italy, pesticide input is particularly high in vegetable crops due to their high level of production costs, short growth cycles, high intensity of cultivation and the required external quality. The quality of produce is very important to guarantee that it will be sold. In general, treatments are considered necessary because the amount of damage tolerated is very small. The first aim in the crop health management is to reduce pesticide input as much as possible without reducing the quantity and quality of production. Preventive measures have been integrated in order to provide the best conditions to avoid the direct control techniques as much as possible, as well to reduce the use of pesticides and pesticide emissions.

Prevention aspects
The most important preventive measures that were taken are:
- crop rotation,
- use of tolerant or resistant varieties,

- use of healthy plant material and seeds,
- maintenance and improvement soil structure,
- optimal fertilisation input, not too high and not too low,
- optimal sowing or transplanting period to avoid certain periods of higher sensitivity for certain pests or diseases,
- optimal management of the ecological infrastructure to preserve or increase functional biodiversity in the environment.

Need for control
Risk was evaluated based on forecasting models, close crop observation, monitoring methods (traps) and damage thresholds. The dynamics of the population, the amount of pests or diseases, and the presence of natural predators were evaluated before taking any decisions.

Control aspects
Preventive applications were applied to control diseases when forecasting models were available. If these warning systems were not available, weather forecasts were used (temperature, rainfall, and humidity) to evaluate the risk of development of disease. For some diseases like powdery mildew, first treatments were done immediately after the appearance of the first symptoms. The applications were optimised with spot-wise applications using efficient application machines, and choosing pesticides with low toxicity, low persistence, high selectivity and effectiveness at low doses to minimise the side effects as much as possible.

4.3.2 Disease control strategies per crop
An overview of the disease control strategies is given in Table 4.4.

Lettuce
In lettuce, wide rotations, good drainage and low plant density reduced the bottom-rot attacks by *Pythium spp., Sclerotinia spp.* and *Botrytis cinerea*. Downy mildew caused by *Bremia lactucae* was not a problem when resistant varieties were used. In the case of humid weather conditions without the use of tolerant varieties, preventive treatments with ***fosethyl-aluminium***, ***metalaxyl*** or copper were necessary to control downy mildew. The last one is the only pesticide that is permitted in the organic system. During the project, treatments against downy mildew were applied only in the first and the last year, as resistant cultivars were not available.

Green beans
To avoid *Rhizoctonia solani, Botrytis cinerea* and *Sclerotinia* spp attacks in green beans, long rotations and good drainage are needed. The control of the green bean foliage pathogens *(Botrytis cinerea, Uromyces appendiculatus)* was achieved with one or two treatments of copper or other synthetic pesticides. Copper is the most common fungicide used to prevent this kind of disease and the only one permitted in the organic system. In autumn, the risks of diseases are higher than in summer. However, if the period was not particularly rainy, then disease treatments were not necessary.

Melon
In melon, long rotations and good drainage eliminated problems with *Sclerotinia* spp., *Verticillium* spp. and *Didymella bryoniae*. Generally, the control of powdery mildew *(Erysiphe cichoracearum, Sphearotheca fuliginea)* did not need specific treatments because tolerant cultivars were available. If resistant varieties are not used, some sulphur treatments are sufficient to control the disease. Synthetic pesticides are needed only in specific cases. In early growing cycles, it was possible to eliminate attacks of downy mildew *(Pseudoperonospora cubensis)*, which normally appeared at the end of summer. As there are no effective curative chemicals, it was important to treat as soon as the conditions were favourable for the disease. In the integrated system, there was a preference for ***fosethyl-aluminium*** and ***cymoxanil***, in the organic system the only possibility was the use of copper.

Strawberry
Long rotations and excluding susceptible species like Solanaceae from the rotation were important to eliminate soil-borne diseases in strawberry, caused by *Fusarium, Verticillium*, *Rhizoctonia* and *Phytophtora*. The main fungal pathogen of Strawberry is *Botrytis cinerea*. The chemical means available in the organic systems are not effective to control this disease. It was important to prevent the disease from developing, using tolerant varieties, low planting density and spot-wise irrigation. In the integrated systems, two or three preventive treatments were applied from the beginning of flowering with ***procymidone***, ***fludioxonil*** + ***cyprodinil***, ***fenexamid*** or ***pyrimethanil***. Sulphur and ***penconazole*** were used in autumn to prevent powdery mildew *(Oidium fragariae)* infections on susceptible varieties. In the organic system, if necessary, powdery mildew can be well controlled by sulphur. *Mycosphaerella* is controlled by copper.

Cauliflower
Risks of infections in cauliflower of *Peronospora brassicae, Alternaria spp.* and *Albugo candida* were greatly reduced with agronomic methods such as long rotations, tolerant varieties and the removal of spontaneous crucifers near the crop. When the first spots appeared, the infections were chemically controlled by copper or, in integrated systems, by synthetic pesticides ***(metalaxyl*** or ***difenoconazole)***.

Fennel
In fennel, bacterial and fungal diseases *(Erwinia carotovora, Sclerotinia spp.* and *Cercosporidium punctum)* can be controlled with agronomic methods such as long rotations and good drainage. Only in the case of a very

humid season, one or two treatments with copper were necessary.

Spinach
The main spinach fungal diseases are downy mildew *(Peronospora farinosa)* and anthracnose *(Colletotrichum dematium f. sp. spinaciae)*. Long rotations (at least three years), destruction of infected crops residues as well as the use of healthy seeds and tolerant varieties were very important to reduce the risk of infection. If resistant cultivars are not available, at least one treatment with ***metalaxyl*** was necessary against downy mildew in the integrated system.

Tomato
Downy mildew *(Phytophtora infestans)* is the main threat to tomatoes. The crop protection management was aided by a forecasting system that can predict the periods of high risk of infection. In that case, preventive treatments were carried out with copper or, in the integrated system, with ***azoxystrobin***, ***metalaxyl***, ***cymoxanil***, ***famoxadone***, ***dodine*** or ***dimethomorph***. Bacterial dis-

Table 4.4 Overview of the most important disease control strategy for each crop

		Prevention						Need for control			Chemical control		
Crop	Disease	Crop rotation[1]	N-Fertilisation[2]	Seeds/plants[3]	Choice of variety[4]	Plant distance[5]	Incorp./removal of residue[6]	Signal[7]	Damage threshold[8]	Guided control[9]	Seed plant treatment[10]	Preventive/ Curative[11]	Full field/row/spot[12]
Lettuce	downy mildew	-	X	X	XX	X	-	-	-	-	-	P	FF
	root-rot	XX	XX	-	-	XX	X	-	-	-	X	P	FF
Green beans	grey mildew	-	XX	-	X	XX	-	-	-	-	-	P	FF
Melon	powdery mildew	-	X	-	XX	-	-	X	-	-	-	P/C	SP/FF
	dydimella	X	X	-	-	-	X	X	-	-	-	P/C	SP
Fennel	bacterial disease	X	XX	-	-	XX	X	-	-	-	-	P	FF
Cauliflower	downy mildew	-	-	-	-	X	-	X	-	-	-	P/C	FF
Strawberry	grey mildew	-	XX	-	-	XX	X	-	-	-	-	P	FF
	powdery mildew	-	X	-	X	-	-	X	-	-	-	P/C	FF
Celery	*septoria*	-	-	-	-	X	X	-	-	-	-	P	FF
Spinach	downy mildew	-	-	-	XX	X	-	-	-	-	-	P	R
Tomato	downy mildew	-	-	-	-	-	-	-	-	XX	-	P/C	FF
Sugar beet	*cercospora*	-	-	-	XX	-	-	X	X	XX	-	P/C	FF
	powdery mildew	-	-	-	X	-	-	X	-	-		P/C	FF

All chemical control only applied in the integrated systems
XX = very effective or available
X = limited effective and/or manageable
\- = not relevant or possible

1. Is crop rotation effective as a preventive measure?
2. Is nitrogen limitation effective as a preventive measure?
3. Is infestation control or selection of seeds or plant effective?
4. Are there resistant or tolerant varieties available and used?
5. Does plant distance influence infections?
6. Is quick removal or incorporation of residues of the crop used?
7. Does control only takes place after detection of the disease and is this effective?
8. Is it possible to use a damage threshold?
9. Are there any guided control systems used?
10. Is plant or seed treatment used?
11. Is it possible to use preventive or curative fungicides?
12. Are pesticides applied in the field: FF = full field, R = row or band application, SP = spot-wise?

eases had to be prevented with copper treatments or by using tolerant cultivars.

Sugar beet
The main pathogen to the sugar beet's foliage is *Cercospora beticola*. It is possible to reduce or eliminate treatments by using tolerant varieties and damage thresholds. If necessary, one or two treatments with copper or, in the integrated system with synthetic pesticides (e.g. ***prochloraz***, ***difenoconazole***, or ***propiconazole***) were done. Powdery mildew could be successfully controlled with one or two sulphur applications.

Wheat
In the integrated system, the control of the most common wheat fungal diseases was based on the use of seed treatments. Agronomic methods are very important to prevent diseases caused by *Fusarium*, *Erisiphe* and *Puccinia*. It was possible to avoid chemical treatments by paying attention to correct fertilisation, sowing density and tolerant varieties.

Celery
In celery *Septoria apiicola* was a big problem. It was important to choose less susceptible varieties. Agronomic methods, for example, long rotations were very important to reduce the disease. The biggest risks for infections occur during spring and autumn. There are no curative chemicals allowed. Therefore, when the first symptoms appeared, treatments with fungicides such as copper, ***dodine*** or ***difenoconazole*** were needed. Autumn 1999 demonstrated the need for these preventive pesticides, as the entire production was lost because of the very humid conditions.

4.3.3 Pest control strategies per crop
An overview of the pest control strategies is given in Table 4.5.

Lettuce
Aphids are the biggest problem for lettuce. The most damage occurs in springtime. During the summer, aphid attacks are less frequent and severe. In the case of heavy infestations, it is very difficult to grow an aphid-free product. Aphid control is very difficult with the means available in organic agriculture. The use of silver-coated film is not feasible and does not always assure good results in aphid control. *Chrisoperla carnea* has been tested as predator but, in addition to not being a completely satisfactory control, this method appears to be too expensive. In the case of heavy infestations, a large number of treatments with pyrethrins can be carried out, but a good control is not guaranteed because of the very low tolerance threshold. In the integrated system, pyrethroids (***deltamethrin***, ***fluvalinate***) can be used. ***Pymetrozine*** and ***heptenophos*** are preferred when aphids are protected among the lettuce leaves. In the organic system, *Autographa gamma* attacks in autumn can be controlled by ***Bacillus thuringiensis*** or ***azadiractin***, in the integrated system pyrethroids can be used as well.

Green beans
Aphid infestations in springtime, if not controlled, can cause problems in green beans, not only in the quantity, but also in the quality. In the organic systems pyrethrins are effective for aphid control, but it seems to be possible to avoid any specific treatments in many cases by using natural control. In the integrated system, treatments with pyrethroids are occasionally needed. The European corn borer (*Ostrinia nubilalis*) is not a dangerous insect for green beans sold in fresh markets. However, its control is the main problem for beans to be sold as industrial crops. The flights of the adult insects are monitored with the aid of pheromone traps to decide when the treatments need to start. Chemical treatments are normally used until harvest with insecticides such as ***etofenprox***, ***deltamethrin***, ***lambda-cyhalothrin*** or ***Bacillus thuringiensis***. Other insects that can cause problems in autumn are the noctuids, controlled by the same pesticide used against *Ostrinia nubilalis*. Red spider mites (*Tetranychus urticae*) infestations can occur on green beans especially when the crop is near a strawberry field. However, the insects can be controlled with localised release of the natural predator *Phytoseiulus persimilis* and normally they are not a problem in a balanced system. If necessary, red spider mite infestations can be controlled with a specific acaricides (***hexythiazox***).

Melon
Aphids (*Aphis gossypii*) can completely destroy the production of sensitive melon cultivars. In the organic system, there are no effective means of control. Therefore, treatments are started as soon as possible against this harmful aphid on young melon plants with pyrethrins or ***azadiractin***. From the end of June, natural control is possible with useful insects (ladybirds). In integrated systems, aphids are easily controlled by a single treatment of ***imidacloprid*** or ***pymetrozine*** on sensitive varieties. Red spider mites are dangerous when it attacks the melon plants before the start of production, but the insect can be controlled both chemically (***hexythiazox***) and ecologically with *Phytoseiulus persimilis* releases. In the organic system, as no effective pesticide is available, constant observation of the crop is very important. However, due to natural control, the red spider mites are normally not a large problem.

Strawberry
In strawberry, it is important to reduce harmful infestations, especially of red spider mites by removing the old vegetation at the end of winter. Aphids, red spider mites and noctuids are the most common pests in this crop. Aphid infestations can occur in springtime and can be controlled with pyrethrins (organic systems) or pyrethroids (integrated systems), but it is not always necessary to treat due to natural control. Aphids can also be

controlled ecologically with the predator *Chrisoperla carnea*. The infestations of red spider mites (*Tetranichus urticae*) in autumn are more frequent. In the integrated systems, they can be controlled either with acaricides (***hexythiazox***, ***fenpyroximate***, ***fenazaquin***, ***tebufenpyrad*** or ***clofentezine***) or with Phytoseiulus persimilis releases. In the organic system, the biological control is the only effective method allowed, but natural control is generally enough. To control the noctuids (*Agrostis spp.*), it is possible to use ***Bacillus thuringiensis*** or ***metaldehyde*** poisoned baits.

Fennel

In fennel, aphids are unusual in the organic system and normally controlled by useful insects like ladybirds. Slugs from nearby ditches caused some damage after transplantation. The use of ***metaldehyde-***poisoned baits makes it possible to overcome this problem in the first years. In the following years, biological control of slugs by ducks was preferred. To treat damage caused by noctuid larvae, one or two treatments with ***Bacillus thuringiensis*** were used.

Table 4.5 Overview of the most important pest control strategy for each crop

		Prevention				Need for control			Chemical control	
Crop	Pest	Crop rotation[1]	Choice of variety[2]	Natural control[3]	Biological Control[4]	Signal[5]	Damage threshold[6]	Guided control[7]	Seed/plant treatment[8]	Full field/row/spot[9]
Lettuce	aphids	-	X	X	-	X	-	-	-	FF
	noctuids	-	-	-	-	X	-	-	-	FF/SP
Green beans	aphids	-	-	X	-	X	X	-	-	FF
	red spider mites	X	-	-	X	X	X	-	-	FF
Melon	aphids	-	X	X	X	X	-	-	-	FF/SP
	red spider mites	X	-	-	X	X	X	-	-	FF
Cauliflower	flea-beetles	-	-	-	-	X	-	-	-	FF
	noctuids	-	-	-	-	X	-	-	-	FF
Strawberry	aphids	-	-	X	X	X	X	-	-	FF/SP
	red spider mites	X	-	-	X	X	X	-	-	FF
Celery	noctuids	-	-	-	-	X	-	X	-	FF
Spinach	noctuids	-	-	-	-	X	-	-	-	FF
	c. mendicus	-	-	-	-	-	-	-	-	FF
Sugar beet	wire worms	X	-	-	-	X	X	X	X	R
	flea-beetles	-	-	-	-	X	X	-	X	FF
	conorrhinchus	X	-	-	-	X	X	X	-	FF
Wheat	aphids	-	-	X	-	X	X	-	-	FF
Various	slugs	-	-	X	X	X	-	-	-	R

XX = very effective or available
X = limited effective and/or manageable
\- = not relevant or possible

1. Is crop rotation effective as a preventive measure?
2. Are there resistant or tolerant varieties available?
3. Is natural control important?
4. Is direct biological control applied?
5. Is it possible to wait until the pest can be detected?
6. Damage threshold = is there one available?
7. Guided control = are there any guided control systems?
8. Is planting or seed treatment used?
9. Are pesticides applied in the field: FF= full field, R = row or band application, SP= spot wise?

Spinach
In spinach, a lot of attention has to be paid to controlling caterpillars (noctuids). Their presence in the harvested product makes it unsuitable for the industrial market. In the integrated system, caterpillars are controlled by ***deltamethrin*** and ***Bacillus thuringiensis***. Aphids are unusual and easy to control.

Sugar beet
Many harmful insects can attack sugar beets. Wireworms (*Agriotes spp.*) can cause severe damage. If any risk of an attack exists, it is better to postpone sowing. In the integrated systems, geo-disinfestation with ***benfuracarb, carbosulfan*** and ***imidacloprid*** allows for good control of wireworms as well as of flea beetles and Pigmy mangold beetle (*Atomaria linearis*). During the project, wireworms were present at a low level. It was possible to avoid the geo-disinfestation because of seed treatment with ***imidacloprid***. For the control of the sugarbeet weevils (*Temnorrhinus mendicus*), it is possible to use vase traps to determine the amount. If the threshold is exceeded, then localised treatments are done with pyretroids near the ditches. The aphids do not need specific treatments because they are controlled with ladybirds.

Tomato
Wireworms (*Agriotes spp.*) can cause great damage to tomatoes. If any are caught with the vase traps, it is recommended to apply spot-wise treatments in the rows with insecticides such as ***tefluthrin*** in the integrated system. Aphids seldom cause direct damage. However, it is necessary to treat with ***imidacloprid*** or ***fluvalinate*** as soon as the threshold is exceeded (10% of plants infested). Noctuids (*Heliothis armigera*) cause damage only occasionally and can be controlled with ***Bacillus thuringiensis***.

Wheat
In wheat, the control of insects needs less attention. Natural predators normally control aphids. During the project, no treatments for insects were necessary for wheat crops.

Celery
Liriomyza huidobrensis can cause a lot of damage in celery, however, in this project, this pest never appeared. As a control in the integrated system, it is possible to use the insecticides ***cyromazine*** and ***abamectine***. Biological control is possible by the hymenopterous parasite *Dygliphus* isaea. Caterpillars of noctuids can cause a lot of damage. If caterpillars are found, it might be necessary to treat with pyrethroids or ***Bacillus thuringiensis***.

Cauliflower
In the case of pressure due to flea beetles (e.g. *Phyllotreta spp.*) in young cauliflower plants, it is possible to treat with pyrethroids in the integrated system. ***Bacillus thuringiensis*** is effective against *Pieris brassicae*, but only on young caterpillars. In the case of bigger larvae, near the harvest, it could be necessary to use pyrethroids to eliminate problems on the final products.

4.4 Testing and improving

In Italy, crop protection in the VEGINECO systems was designed to lower the level of pest, disease and weed control, and utilise products with lower toxicity for humans and the environment. Furthermore, the project focused on reducing the number of applications and the amount of pesticides as much as possible. It is possible to evaluate the efficacy of the crop protection strategy by considering the quantity (QNP) and the quality (QLP) of the production, the input (PESTAS) and emission (EEP) of the applied pesticides (see Annex 2 and 4).

Control strategies, quality production costs and manual weeding
Productive aspects have been evaluated in comparison with targets for I INT2 based on good agricultural practice and production averages of single crops. For I ORG, targets were based on the experience of technicians working at the organic farms. The results are summarised in Figures 4.1 to 4.3 and Table 4.6.

I INT1
In I INT1, the quality production of melon was influenced by the crop protection strategy. In this crop, QNP and QLP values were lower than the targets, especially due to wireworms and viruses. Other reductions of QNP were due especially to the weather conditions (dry climate in wheat in 2000 and low fruit setting in green beans).

I INT2
In I INT2, the negative influence of pests and diseases on QNP and QLP was particularly evident. A low average QNP and QLP in celery was due to a failed harvest in 1999 caused by serious infection of *Septoria apiicola*, which could not be controlled with the products, allowed under the integrated guidelines. However, in conventional production, *Septoria apiicola* also caused serious damage in 1999. During 2000, some damage was seen on celery due to noctuids, but the harvest was acceptable to the processing industry without any depreciation in value. Lettuce had some problems linked to pest and disease control as well and this negatively influenced the level of QNP for this crop, particularly the summer and autumn cycle. During the first summer, aphid control was very difficult and the market did not accept the first resistant varieties. For these reasons, the average level of QNP and QLP was lower than the target. During the autumn cycle of 1998, the resistance against *Bremia lactucae* of the variety chosen was reduced due to the appearance of new strains of this disease. The chemical control was not satisfactory and this negatively influenced QNP and QLP. In the autumn cycle, the QNP and QLP values were reduced slightly due to noctuids. Other causes of low

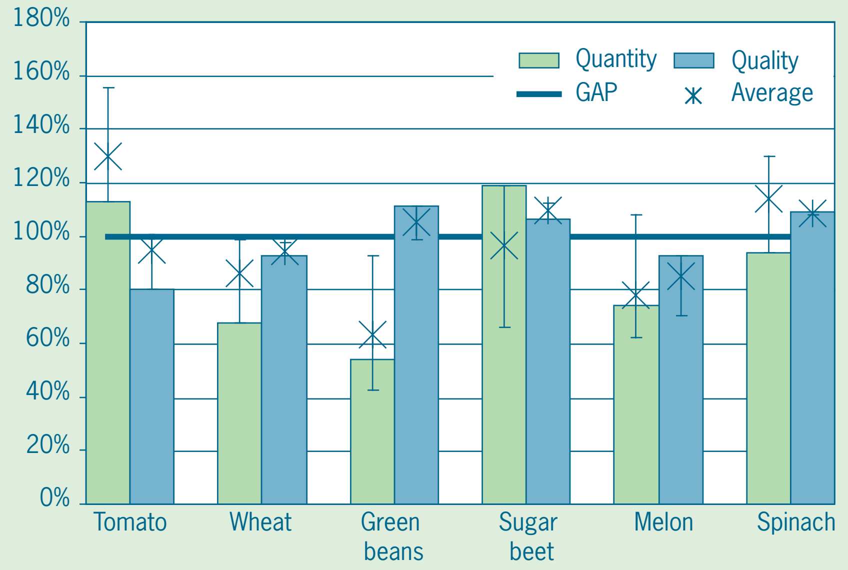

Figure 4.1 Level of quality production (2000) achieved per crop compared to GAP production in I INT1 (quality sugar beet expressed as sugar content instead of % quality class 1)

QNP levels related to crop protection were a serious mouse problem (cauliflower 1999) and inefficient weed control (green beans 1997).

I ORG

In I ORG, the situation was better compared to the other systems even with less use of active protection. This is partly because of lower targets for product quality; the market pays the same price not only for top quality, but also in some cases also for second quality. Additionally, natural predators and the non-chemical protection strategy (slugs controlled with ducks, geese and turkeys) contributed to good results.

Autumn lettuce and strawberry had relatively low QNP. In addition, the problems stated for I INT2, an attack of wireworms in lettuce (*Agriotes litigiosus*) caused loss of 25% in some areas in the fields in 1998.

Strawberry showed a low QNP level in 2000: this was probably due to the catch crop ploughed in 1999, which produced toxic substances during its decomposition. *Botrytis cinerea* caused quite a lot of damage depending on the variety in this crop.

In green bean, the level of QNP was good. Presence of aphids, however, did not permit harvesting in some areas of the particular field. The red spider (1997) was very well controlled with *Phytoseiulus persimilis*.

Melon's results were good due to the utilisation of resistant varieties against powdery mildew and *Aphis gossypii* (against this pest, good results have also been obtained with the use of *Phytoseiulus persimilis*). A good result in quality was partially due to good trends in the markets. For example, classifications in quality classes do not exist for lettuce and all of the products are sold for the same high price. The price for strawberry is high because the product that is not sold to the fresh market can be sold to industry as top quality products.

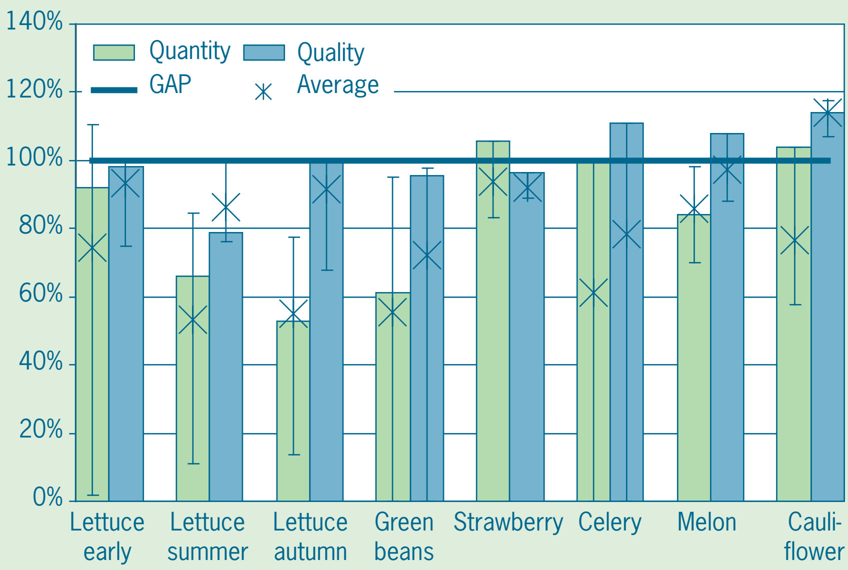

Figure 4.2 Level of quality production (2000) achieved per crop compared to GAP production in I INT2

The influence of weed control on QNP and QLP in I INT2 was very limited. The exception was green beans in the first year, when a large amount of *chenopodium* could not be controlled. In all situations, weed control required a lot of manual labour (especially in celery, lettuce and strawberry) or use of herbicides (major part of the crops).

In I ORG, problems with low QNP and QLP values linked to weed control have not been registered because the control was done normally at the right time with a large amount of manual labour hours, often due to the lack of specialised machinery. Only in 1998, weed control in green beans was not effective because the crop was covered with a film of A grovel, which did not permit manual weeding. For this reason, the crop was ploughed under and sown again later. Of course, this accounted for major economic losses.

In Figure 4.4, fennel, strawberry and green beans were the crops that needed the most hours manual weeding. The year 2000 had the highest number of manual labour hours because of the density of *portulaca* increased by the favourable weather conditions, especially in fennel and green beans.
In I INT1, weed control was necessary especially to control the weeds in spinach and to control *Solanum nigrum* on tomato and *Sorghum halepense* on melon and tomato. The weeds lowered the QNP for spinach in 2000 because the herbicide was not completely effective and a part of the field was not harvested.

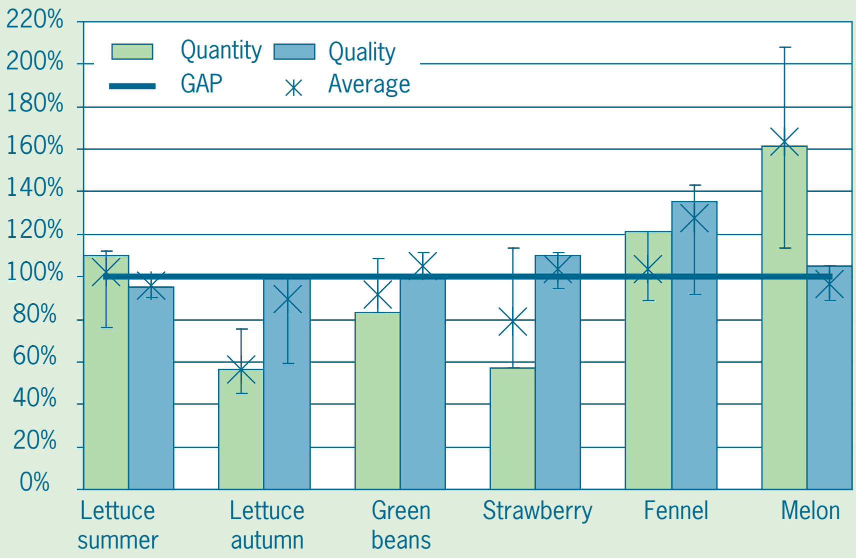

Figure 4.3 Level of quality production (2000) achieved per crop compared to GAP production in I ORG

Pesticide use, emission and damage risks

In the organic system in 2000, there was a dramatic decrease in the number of treatments (from 22 to 4) and in the input of active ingredients in comparison with 1997 (Table 4.7). In I INT2, the main reduction of pesticide input was in the group of insecticides and, for a lesser extent, in the group of herbicides.

The total active ingredient input in 2000 (3.6 kg ha^{-1}) was higher than the target value (3.2 kg ha^{-1}) because of the humid autumn and the loss of lettuce varieties resistance to downy mildew. This required the use of more fungicides than in the previous years.

Table 4.6 Pest and disease causes of shortfall in quality production

System	Crop	Shortfall caused by	disease/pest cause	Shortfall in strategy
I INT1	Green beans	QNP, not harvesting QLP, pest damage the beans	aphids	Control timing
I INT2	Lettuce	QNP and QLP, losses of external leaves	*bremia lactucae*	Availability of resistant variety Fungicides efficiency
			aphids	Choice of resistant variety Control frequency
			noctuids	Control frequency
	Celery	QNP loss of plant, insufficient development and cutting of apical portion	*septoria apiicola*	Control frequency Fungicides choice and efficiency Resistant varieties not available
			noctuids	Control frequency
I ORG	Lettuce	QLP, low plant development and loss of plants	wire-worms	No efficient control available
	Strawberry	QNP, fruits rotting	*botrytis cinerea*	No efficient control available
			fungi living on the ground	Cover crop management before planting

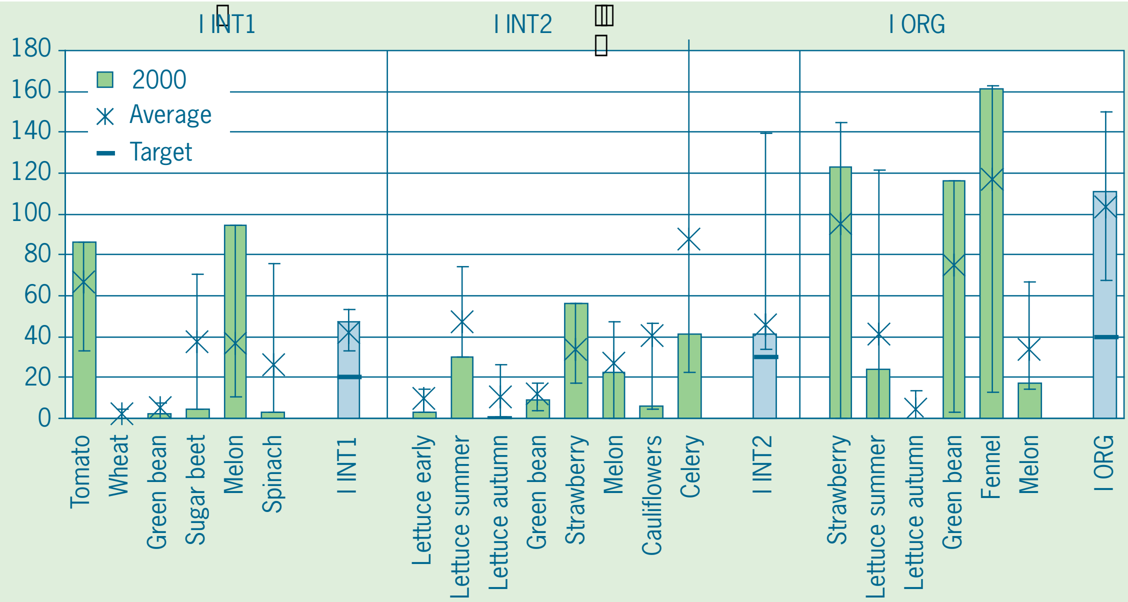

Figure 4.4 Hours of manual weeding per crop (hours ha^{-1})

In I INT1, the input of synthetic insecticides and fungicides was very low in the year 2000 as in the previous years. The main problem was the herbicides input in spinach that caused higher EEP levels. The results of the last year showed a dramatic reduction of the EEP level compared with conventional practice. The target for EEP air and soil, 30% of the conventional level, was achieved. Problems remained in I INT1 for EEP groundwater due to lack of herbicides with low leaching risks.
Different aspects of the applied strategies (Tables 4.8 to 4.10) caused the reduction in use and emission.
Important elements in the reduction of use and emissions

Table 4.7 Parameters related to pesticides use and emissions

	Number of Applications no. ha^{-1}	Active ingredient input kg ha^{-1}	EEP air kg ha^{-1}	EEP groundwater ppb	EEP soil kg days ha^{-1}
I INT1					
Conventional 2000	34	6.2	1.17	16.02	432
Actual 1997	19	2.7	0.43	8.26	190
Actual 2000	15	1.4	0.37	8.99	145
VEGINECO target		3.1	0.35	0.5	130
% reduction 2000 - conventional	56	77	68	44	66
I INT2					
Conventional 2000	65	10.7	3.57	92.12	998
Actual 1997	31	4.7	1.33	35.01	418
Actual 2000	15	3.6	0.52	0.00	95
VEGINECO target		5.4	1.07	0.5	299
% reduction 2000 - conventional	77	66	85	100	91
I ORG					
Conventional 2000	54	6.5	1.67	17.03	300
Actual 1997	22	1.2	0.31	0.00	7
Actual 2000	4	0.0	0.01	0.00	0
VEGINECO target		0.5	0.20	0.50	25
% reduction 2000 - conventional	93	100	99	100	100

Table 4.8 Main differences in herbicide inputs between conventional and actual VEGINECO 2000

Crop	Application type	Conventional pesticide	Pesticide 2000	Difference in strategy (2000)
Green beans		***linuron***	***linuron***	Lower Dose
Sugar beet		***metamitron*** ***phenmedipham***	Goltix Betanal progress	Lower Dose Lower Dose
Tomato	Post-transplantation	***pendimethalin***		Better mechanical control
Wheat		***linuron*** ***tribenuron-methyl***	-	Mechanical control Spiked chain harrow
Celery		***trifluralin***	-	Better preparation of seedbed
Cauliflower		***propachlor***	-	Mechanical control and ridging
Lettuce		***propyzamide***	-	Lower Dose or elimination through mulching

Table 4.9 Main differences in fungicide inputs between conventional and actual VEGINECO 2000

Crop	Disease	Conventional fungicide	Pesticide 2000	Difference in strategy (2000)
Strawberry	bacteria	***dithianon*** copper	-	Close observation, no application necessary
	Micosphaerella	copper	-	Close observation, no application necessary
	powdery mildew	***penconazole*** sulphur	sulphur	The natural a.i. (sulphur) is considered enough to contain the damage below threshold
	fruit rot	***procymidone*** and others	***pyrimethanil***	Reduced number of treatments, choice of reduced emissions pesticide
Lettuce	downy mildew	***metalaxyl*** copper ***fosethyl-aluminium***		The loss of resistance required more specific treatments in 2000, but at a lower number than in conventional
	bottom rot (*B. cinerea*)	***procymidone***	-	No application necessary due to the rotation
Melon	powdery mildew	***penconazole*** sulphur	-	Close observation, no application necessary due to the use of resistant varieties
Sugar beet	*Cercospora beticola*	***fentin acetate*** ***propiconazole*** ***nuarimol*** and others	-	No application necessary (damage threshold) due to the use of tolerant varieties
	powdery mildew	***propiconazole*** sulphur	sulphur	Choice of more favourable pesticides. Sulphur is sufficient
Tomato	downy mildew	copper, ***cymoxanil***, ***metalaxyl***, ***dimethomorph***, ***dodine***, ***chlorothalonil*** and others	copper ***cymoxanil***	Lower number of treatments due to the regional warning systems
Spinach	downy mildew	***metalaxyl*** copper	-	No application necessary due to the use of resistant varieties
Celery	*Septoria apiicola*	***chlorothalonil*** copper	***dodine*** copper	Choice of more favourable pesticides, lower frequency of application

were close observation of the crops, the use of traps and damage thresholds, use of resistant or tolerant cultivars, use of crop rotation, pesticides choice based on EEP, spot-wise applications and maximum use of non-chemical control methods (especially natural control).
Chemical control of weeds was abandoned in I ORG, where herbicides were replaced by mechanical and physical treatment. This, however, resulted in more hours of manual weeding. In the integrated systems, the reduction of the emission of herbicides was achieved by better integration of mechanical weed control, low dosage systems and a better choice of pesticides.

Most of the reduction in use and emission of pesticides used for disease control is due to the use of resistant or tolerant varieties (lettuce-downy mildew, melon-powdery mildew, sugar beet-*cercospora* and spinach-downy mildew). Moreover, reduction was caused by lower frequencies and lower doses per application usually due to closer observation of the crops (strawberry-powdery mildew, celery-*septoria* and sugar beet-powdery mildew), the use of forecasting models (tomato-downy mildew and sugar beet-*cercospora*) and the use of damage thresholds (sugar beet-*cercospora*).
Concerning pest control (Table 4.10), the most important reasons for reduction in use and emissions are the use of resistant varieties (melon-aphids and lettuce-aphids), lower frequency of applications and better choice of pesticides. The lower frequency is based on close observations of the crop (aphids in melon, green bean and lettuce) and damage thresholds (*Conorrhinchus* in sugar beet and aphids in strawberry and wheat). Pests controlled with natural predators proved very important, especially in the organic system. Natural control can be improved by increasing the amount of natural elements like shrubs.

Table 4.10 Main differences in insecticide inputs between conventional and actual VEGINECO 2000

Crop	Pest	Pesticide conventional	Pesticide 2000	Difference in strategy (2000)
Strawberry	red spider mites	***hexythiazox***, ***fenpyroximate***	-	Presence below damage threshold
	aphids	***heptenophos***	-	Close observation, no application necessary
	flee-beatles noctuids	***acephate***	-	Close observation, no application necessary
Melon	aphids	***imidacloprid***	-	No application necessary due to the use of resistant varieties
Sugar beet	wire-worms flee-beatles	***terbufos*** ***imidacloprid***	***imidacloprid***	Lower input due to the seed treatment instead of soil treatment
	aphids	***deltamethrin***	-	Close observation, no application necessary due to the use of natural control (ladybirds)
	Conorrinchus mendicus	***azinphos-methyl*** ***deltamethrin*** and others	***deltamethrin***	Lower input due to the use of traps and thresholds Use of a.i. less toxic for humans
Tomato	aphids	***imidacloprid*** ***methomyl*** ***fluvalinate***	-	Close observation, no application necessary due to the use of natural control (ladybirds)

5 A practical case of crop protection strategies in the Valencian Community (Spain)

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5.1 Introduction

The Valencian Community (VC) has always been a traditional area for vegetable crops in Spain. In 1998, this group of crops was the second most important crop in economic value after citrus. The use of manual labour in Valencian horticulture is enormous; approximately 50% of production costs are due to manual labour. Vegetables are complementary to citrus, because vegetables require the largest amount of the manual labour in periods of low activity in citrus orchards, contributing favourably to better distribution of manual labour and fixed costs of facilities. In the past years, greenhouses are continuously expanding in the south. Therefore, field-grown vegetable crops are more important in the centre and north of the Valencian Community.

The most important crops are tomato, potato, onion, watermelon, artichoke, lettuce, melon, pepper and cauliflower. The South of the Valencian Community is one of the most important areas in Europe for tomato.

It is very important to take into consideration the small size of the farms in order to understand the real situation of vegetable crops in the Valencian Community. This helps to understand the great demand for manual labour as well as the scarce availability of machinery to mechanise farm activities, mainly weeding. The average size of farms in the Valencian Community is about 4.5 ha. More often the farms are combining vegetable crops with other kind of crops that have lower manual labour needs such as citrus or other fruit crops.

In the last ten years, the regional government has heavily promoted integrated production and the process of change in thoughts and behaviour gradual. The main problem for introducing integrated management in commercial farming is the high demands in external quality and, in some cases, the lack of alternatives to conventional farming techniques.

Although organic, field-grown vegetable farms are still a relatively small sector, its share is growing, slowly but steadily. The main market for organic produce is international. In both cases, organic and integrated farming, the need for development of new crop protection techniques and strategies is clear, as well as the transfer of these techniques to commercial farms.

Five integrated farming systems were tested from north of the Valencian Community (VC) in Benicarló (ES INT2) to south in Pilar de la Horadada (ES INT1) in the most important vegetable growing areas of the VC. In Paiporta, in addition to the integrated system ES INT3, an organic system (ES ORG) was tested. The rotation of both systems was the same in order to compare the results. At the two other locations, the development of integrated systems was hampered due to several structural reasons such as lack of experience, changes of personnel and sometimes lack of manual labour.
In the other systems, to serve as a base for a global strategy, a crop rotation system was established (see the manual on prototyping methodology and multifunctional crop rotation). The rotation was designed including the most common crops in the different areas, the botanical families of these crops and their characteristics. The rotations for the year 2000 are shown in the Table 5.1.
In the following section, stable strategies for crop protection are defined based on the work done over two and a half years in the three integrated and one organic farming systems.

5.2 Weed control strategies

5.2.1 General weed control strategies

General
The main objective in the integrated systems was to reduce the use of herbicides without increasing the hours of manual weeding. In the organic system, the strategy was to minimise the hours of manual weeding as much as possible.

It is important to estimate the level of weed infestation in

Table 5.1 Composition of crop rotations in the Spanish systems in 2000

Year	ES INT1	ES INT2	ES INT3 and ES ORG
1	green manure - pepper - little gem	artichoke	artichoke
2	little gem - sweet corn - broccoli	tomato - green bean	green bean - onion
3	iceberg lettuce - onion	lettuce - lettuce - watermelon	watermelon - cauliflower - potato
4	celery - watermelon	cauliflower - green manure	fennel - green manure

the plot (low, medium or high) before deciding on the strategy for control. The need for the use of herbicides is greater in integrated systems with medium and high levels.

The strategy was changed depending on the infestation level. In all systems, the infestation level was classified:
- ES INT1 level 3 (medium-high),
- ES INT2 level 1 (low),
- ES INT3 level 2 (medium-low),
- ES ORG level 2 (medium-low).

The timing of manual and mechanical weeding was the main factor for the success or failure of the strategy. Other important aspects were the availability of machinery and tools, as well as the farmers' experience with mechanical weed control.

Prevention aspects

Seedbed preparation was usually adapted to the available machinery to reduce mechanical control during crop growing periods. Green manure crops were used as a means of preventing weeds because of their ability to compete with weeds. As much as possible, weeds were prevented from seeding to lower weed pressure in following crops. When seeding did occur once in a crop, the infestation level went directly from level 1 to 4.

In the design of the crop rotation, the time needed to do false sowings or the best period to carry them out was not taken into account. The construction of the crop rotation was not focused on weed control because a higher priority was given to pests and disease prevention.

Aspects of control

The mulching with black plastic proved to be effective. If considering its use, the following items should be taken into account: the effect on the environment, the increase of costs and whether or not this type of mulching is practical for a specific crop.

In order to maximise the use of mechanical methods, for example a walking tractor, the distance between plants must be adapted to the available machinery (as stated in 'prevention'). The use of the roto-tiller and/or cultivator is the most common practice in between crops. During crop growth, a walking tractor (with a hoe, a middle breaker or a little roto-tiller as tools) is used to do the mechanical control. It is essential to do both mechanical and manual weeding at the right moment (timing), when volunteer plants appear. Weed control is much more difficult from end of spring until the beginning of autumn because weed development is very fast during this time of year.

In the integrated systems, it was preferable to use contact herbicides when chemical control was necessary, although there are very few available for vegetable crops.

Table 5.2 Overview of available machinery in the Spanish systems

Machine	Type	Width m	Row spacing m	Crops
ES INT1				
Rotary hoe	soil cultivation	1.7	all	all
Cultivator	harrow	1.75	all	watermelon, all possible
Breaker plough	soil cultivation	1.5	all	all possible
Mulcher	mulching	0.6-1.1	all	watermelon, lettuce, pepper, sweet corn
Ridger	prepare planting	1	1	all except watermelon
ES INT2				
Rotary hoe	soil cultivation	1.5	all	all
Middle breaker	inter-row cultivation	0.3	0.5 - 1.2	all except onion, watermelon
Coulter	inter-row cultivation	0.5	0.7 - 1.2	all except onion, watermelon
Cultivator	harrow	1.7	all	watermelon, all possible
Breaker plough	soil cultivation	1.5	all	all possible
Mulcher	-	0.6-1.1	2 - 3	watermelon
ES INT3 and ES ORG				
Rotary hoe	soil cultivation	2.5	all	all
Rotary hoe	inter-row cultivation	1.1	1 - 0.4	all except watermelon
Cultivator	harrow	1.2	3	watermelon,
Ridging plough	ridger	0.4	0.4	green bean, potatoes
Mulcher	mulching machine	0.6 - 2	3	watermelon

Paraquat and ***diquat*** were removed from the group of herbicides because of their environmental and toxicological problems. The choice of the herbicide is made according to its physical properties (see Chapter 2.3, Quantifying Effects of Crop Protection) to minimise the effect on the environment. Likewise, if herbicides were needed, they were used locally (spot-wise or band spray) when the weed infestation level was low enough and the layout of the crop allowed it.

5.2.2 Weed control strategies per crop

Table 5.2 is an overview of the available machinery for physical weed control; Table 5.3 represents a summary of the weed control strategies.

Lettuce

In fields with a low level of infestation, crops could grow in some situations without the use of herbicides. Mechanical weeding together with an input of 33 hours ha^{-1} of manual weeding gave satisfactory results. The use of herbicides was necessary in plots with a medium level of infestation, usually in the summer cycle in which the growth of the weeds is much quicker. When the use of herbicides was necessary, ***propyzamide*** released fewer emissions than the ***pendimethalin*** to soil and groundwater. The black mulch was a good alternative to herbicides in lettuce because it was possible to use the same mulch in two consecutive crops.

In the organic system, with a medium level of infestation, an average of 164 hours per hectare with manual hoeing was needed. The summer cycle required the largest number of manual weeding hours.

The use of mulch in roman lettuce and iceberg, as well as the local use of ***glufosinate*** in the integrated systems, can contribute to the reduction of herbicide applications and the numbers of hours of manual weeding needed.

Cauliflower and broccoli

Integrated weed control without herbicides was possible in plots with a low level of infestation with the aid of mechanical and manual methods (on average 37 hours ha^{-1} of manual labour were necessary). The localised use of ***glufosinate*** was an alternative to the use of chemicals with a lower environmental effect in plots with a low level of infestation. In plots with a medium or high level of infestation, the best results were obtained with ***alachlor*** or ***oxyfluorfen*** as herbicides. ***Propachlor*** was rejected because of its high impact on the environment. In the organic system, an average of 199 hours ha^{-1} of manual weeding was used due to the use of a distance between the plants that was slightly adapted to the mechanical tools, but resulted in a dramatic increase in yield (75%). The localised application of ***glufosinate*** in integrated systems, with high levels of infestation, did not provide good results because the need for manual weeding was excessive (96 hours ha^{-1}). The optimisation of the mechanical methods and the application of black mulch are promising techniques to be developed in the future.

Artichoke

For weed control, ***oxyfluorfen*** was used in localised applications, obtaining good results. It can also be applied in post-transplantation, before budding. The black mulch in the seed-propagated artichoke can be an alternative to herbicides. In the organic system, a mean of 266 hours ha^{-1} of manual weeding was needed.

Pepper (transplantation in April)

In spite of the use of the black mulch in this crop, the lack of herbicides led to an excessive input of manual weeding (an average of 234 hours ha^{-1}). Therefore, in plots with a medium or high level of infestation, it will be necessary to combine manual weeding and mulching with other mechanical and/or chemical methods.

Watermelon

In this crop, a very stable strategy for weed management has been developed both in integrated and organic systems. The combination of black mulch and mechanical methods led to adequate input of manual weeding with an average of 57 and 43 hours ha^{-1}, respectively) even in plots with a high level of infestation.

Tomato (summer – autumn cycle)

In spite of the low level of infestation, the combination of mechanical and manual weeding obtained a moderate result of manual weeding hours (120 hours ha^{-1}). The localised use of ***glufosinate*** with low environmental impact can lower the need for manual labour. Another alternative can be the use of black mulch, which was not used in this crop. The use of ***metribuzin*** in plots with low levels of infestation was discarded due to the high environmental impact.

Potato

Correct mechanical management can reduce the need for manual weeding to very low levels, even in plots with medium levels of infestation. In Paiporta (systems ES INT3 and ES ORG), the average amount of manual weeding hours per hectare was 7 and 8, respectively, without the utilisation of any herbicide.

Fennel (transplantation in September)

Trickle irrigation and the distance between plants used were obstacles in this crop for efficient mechanical control because weeds mainly grew in the cropping rows. Because no herbicides were allowed in this crop, integrated management was very difficult. The input of manual weeding was high in both organic and integrated systems (higher than 120 hours ha^{-1}). ***Pendimethalin*** was not used in the final strategy because it is not authorised and has a high environmental impact.

Onion

In this crop, it was extremely difficult to avoid the use of herbicides. The main reasons are the distance between plants and the characteristics of the crops (poor cover-

Table 5.3 Overview of weed control strategies in some integrated and organic systems of Spain

		Mechanical and physical control					Chemical control			
Crop	Row distance (m)	Harrow	Ridging hoe	Flame	Brush	Soil cover	Spray application[1]	Herbicide type[2]	Low dose technique	Manual labour[3]
ES INT2 (Int. BEN). Weed Infestation level: low (level 1; 1-4)										
Artichoke	1	–	X	–	–	–	SP	C-S	–	3
Cauliflower	0.7 - 1.3 *	–	X	–	–	–	–	–	–	1
Green bean	0.7 - 1.3 *	–	X	–	–	–	–	–	–	0
Lettuce	0.4 - 1 *	–	X	–	–	–	–	C-S	–	4
Onion	0.6	–	–	–	–	–	FF	C-S	–	0
Tomato	0.7 - 1.3 *	–	X	–	–	–	SP	C-S	–	0
Watermelon	2 - 4 *	X		–	–	X	–	–	–	0
ES INT3 (Int. Paiporta). Weed infestation level: medium-low (level 2; 1-4)										
Artichoke	1.20	–	X	–	–	–	–	–	–	10
Cauliflower	1.00	–	–	–	–	–	–	–	–	5
Fennel	0.75	–	–	–	–	–	R	C-S	–	1
Green bean	0.75	–	X	–	–	–	R	C	–	9
Lettuce (2 crops)	0.75	–	–	–	–	–	– / R	– / C - S	–	2 / 2
Onion	0.55	–	–	–	–	–	–	–	–	–
Potato	0.65	–	X	–	–	–	–	–	–	1
Watermelon	3.00	X	–	–	–	X	–	–	–	5
ES ORG (Org. Paiporta) Weed infestation level: medium-low (level 2; 1-4)										
Artichoke	1.20	–	X	–	–	–	–	–	–	14
Cauliflower	1.00	–	–	–	–	–	–	–	–	5
Fennel	0.75	–	–	–	–	–	–	–	–	7
Green bean	0.75	–	X	–	–	–	–	–	–	7
Lettuce (2 crops)	0.75	–	X / X	–	–	–	–	–	–	2 / 20
Onion	0.55	–	–	–	–	–	–	–	–	5
Potato	0.65	–	X	–	–	–	–	–	–	1
Watermelon	3.00	X	–	–	–	X	–	–	–	5

XX = very effective or available
X = limited effective and/or manageable
\- = not relevant or possible

* Planted in double lines; first distance, between simple lines
1. FF = full field; R = row or band spray; SP = spot-wise
2. C = contact herbicide, S = soil herbicide
3. Additional manual labour needed: 1 = < 20 hours ha^{-1}, 2 = 20-40, 3 = 40-60, 4 = 60-80, etc.

age of the soil and very long growing cycles). Herbicide use in this crop represents a notable increment in the hours of manual weeding. Therefore, the strategies of weed control were designed to minimise the pesticide use and emissions by reducing the number of applications, choice of pesticides and adapting the distance between plants to the mechanical weeding machinery that was available.

In a field with four rows per ridge, at a distance of 12 cm between rows and 0.5 m between ridges, the application of herbicides can be restricted to the area covered by the crop (about 50% of the plot surface). This allows for the use of a walking tractor between the ridges during the entire growth period. The use of ***chlorothalonil*** +

propachlor was rejected due to the excessive environmental impact. The main strategy was an application of ***oxyfluorfen*** after transplantation of the crop and after weed emergence, delaying the application with the goal that this could cover a longer period of the crop's cycle. The average of manual weeding was 130 and 492 hours ha^{-1} in integrated and organic systems, respectively. Therefore, it seems necessary to develop new techniques that permit a reduction of manual weeding. The use of burners, the low dosage application technique and testing of new distances between plants are some of the possible alternatives.

Celery
Because there was no adequate machinery in ES INT1, it was necessary to use herbicides throughout the field (***prometryn***). The localised application of herbicide and the use of black mulch could be other alternatives to use together with mechanical methods when they are available.

Green bean
Adapting the distances between plants to the available machinery made it possible to abandon herbicide use in plots with low levels of infestation and not increase the hours of manual weeding. When the application of herbicides was considered necessary, the best option was to use ***glufosinate*** in localised applications. In plots with medium or high levels of infestation, and without adequate machinery for mechanical control, the application of herbicides was necessary. In these situations, the use of ***metobromuron*** was the chemical option that had less impact on the environment. In the organic system, without adapting the distances between the plants to the available machinery, an average of 156 hours ha^{-1} of manual weeding was necessary.

Sweet corn
The combination of black mulch with localised use of ***MCPA*** was the strategy that obtained the best results. When herbicides were not applied, the hours of manual weeding reached very high values (from 115 to 140 hours ha^{-1}).

5.3 Disease and pest control strategies

5.3.1 General disease and pest control strategies

General
Pests and diseases usually can affect vegetable crops in a very rapidly. At the same time, the present market system demands products with good external quality and the small margins make it difficult to take too many risks. Therefore, maximum attention must be paid not only to control pests and diseases, but also to prevent them.

Viruses have become the most harmful problem for vegetable crops in the past few years in the East Coast of Spain. They have even limited the production of some crops, mainly in the most intensive vegetable growing areas. Because curative approaches can not control viruses, preventive measures are preferred in the crop protection strategies.
In the design and development of the crop rotations, emphasis was on prevention of soil-born diseases and the lay out of hedgerows as shelters for the natural predators.

Prevention aspects
While designing, the crop rotations, in addition to the substitution of chemical disinfection of soils, several preventive aspects regarding the pests and diseases were considered:

- Eliminating soil-born diseases by designing crop rotations with crops belonging to different botanical families, with different characteristics and, in many cases, different phytopathologic problems.
- Managing natural predators by establishing hedgerows in all the fields. The hedgerows consist of several plant species and are intended to be used as refuge for the natural predators.
- Avoiding aerial diseases by choosing tolerant or resistant varieties.
- Minimising viruses and pests shifting planting to less sensitive periods.

In other cases, insect nets have been used to eliminate or keep insects that are virus vectors from reaching the crop. Whenever possible, reliable plant and seed producers provided the necessary healthy plants and seeds, free of any disease or pest.

Watering was optimised in amount and timing (not too abundant) to eliminate optimum conditions for soil-born diseases as much as possible. Nitrogen supply was optimised to stop the growth being too lush and therefore, to reduce the plants' sensitiveness both to pests and diseases (see Manual on Integrated and Ecological Nutrient Management).

Need for control
The need for control was established by periodical inspections of the fields (at least once a week during spring, summer and autumn, and every fifteen days in winter). In the beginning, local technicians and farmers were consulted in order to get more information about the need for control due to the lack of economic thresholds and knowledge about epidemiology in certain areas. In the first year, relevant agronomic data from the inspections was recorded in detail to monitor the development of different problems. In addition, the farmers assisted by carrying out extra inspections when needed in cases of maximum risks.

After one and a half-years, the inspections were recorded with less detail, as problems appeared to be very similar and their development predictable. The data collected in the first period of the project was very helpful in decision-making. The lack of scientific references (thresholds) makes decisions quite subjective in some cases.

Control aspects

The main objectives in crop protection strategies for the Valencian systems were:

- to minimise the use of synthetic pesticides,
- to maximise the use of products with a lower environmental impact such as copper, sulphur and other bio-pesticides,
- to study the possibilities of using alternative measures of control (*Trichoderma sp.* for soil fungi diseases and heat treatment in artichoke),
- to substitute soil chemical disinfections with bio-fumigation or solarisation, when necessary,
- to test releases of natural predators for certain pests.

In the applications, mineral oil and pesticides with a lower impact on the environment (pyretroids, ***azadiractin*** or ***Bacillus thuringiensis***) were mixed to increase the impact of these pesticides and to increase their persistence. The choice of synthetic pesticides was, in addition to efficiency, based on their impact on the environment. In the following description, only the main diseases and pests are mentioned. Pests and diseases with almost no impact on yield or quality are not included.

5.3.2 Disease control strategies per crop

Lettuce

Frankiniella sp. appeared very frequently, although the correlation with the incidence of TSWV is not significant. The cultivations at the end of August appeared to be very sensitive to TSWV. The infection with TSWV was always lower than 10% in the plantings from mid-September to January than those done at the end of June.

Downy mildew caused the loss of two entire crops in the winter-spring cycle, although preventive treatments with ***azoxystrobin*** and ***cymoxanil*** were applied. The risk of losing a total crop was too high in the case of *Bremia lactucae*. The first stages of the crop seem to be less sensitive to the disease. The soil-born diseases *Botrytis sp.* and *Sclerotinia* occurred with moderate frequency, although their presence usually was lower than in 5% of plants. Adequate irrigation management appeared to be the best technique to control these diseases. Treatments with ***procymidone*** and ***azoxystrobin*** were also applied, but both had questionable results.

Other diseases such as *Stemphylium sp.*, *Pseudomonas cichorii* and the virus *Big Vein* occurred with low frequencies and low incidences. For the control of *Stemphylium sp.*, several compounds were used (copper, ***azoxystrobin*** and ***difenoconazole***); and *Pseudomonas chichorii* was controlled with copper. *Rhizoctonia sp.* occurred in one case, but this was clearly caused by the excessive depth used for the transplantation. The treatments with ***azoxystrobin*** and reducing the amount of irrigation water were not useful in controlling the disease.

Cauliflower and broccoli

Although ***Xanthomonas campestris*** and ***Peronospora brassicae*** occurred with regular frequency, both crops showed quite a tolerance to these diseases and, in most of the cases, the treatments with copper and fosphyte (mildew) were sufficient for effective control. The varieties of cauliflower used were Dunkeld, Nautilus and Sirente, and Maraton in broccoli. Systemic pesticides were only used when mycelium occurred in abundance and in conditions favourable for the disease. In the organic system, diseases caused no significant losses of production. Two treatments with copper were sufficient to treat a crop with an abundant amount of mycelium.

The reductions of copper treatments for the control of these two diseases did not impact the final yield either. The differences in sensitivity between cultivars to both diseases should be examined for a better control strategy.

Artichoke

The main problem with artichokes was the death of young plants or planting failure. Although *Rhizoctonia solani* impacted planting failure directly, other possible causes of the premature death of plants after sprouting were exhausted soils or the infestation by *Verticilium sp.*. Healthy plant material and disinfection of the cuttings with ***pencycuron*** or ***azoxystrobin*** was very important. In addition, the minimum cropping frequency should be at least 1:4. Growers' experience confirms that fields where artichoke never has been cultivated before had fewer problems with planting failure. Thermal disinfection of cuttings, as a possible alternative to chemical disinfection, is in development. In the organic system, even without any chemical disinfection, planting failure was not greater than in the integrated system.

Oidium frequently causes problems for artichoke at the end of winter or in springtime. Although it can cause some decay in the plants, its impact on produce is considered minimal and, therefore, intervention is not necessary. Sulphur can be used to control the disease for produce intended for fresh markets.

In one case, seed-propagated artichoke was also infected by *Verticilium sp.* reducing the crop yield by 50%. This cultivation type has been shown to be much more susceptible to Oidium, and although only sulphur was used to control the disease, the decay of the plants was much higher than in the cutting cultivation type. Therefore, it could be necessary to use curative fungicides for Oidium control in seed-propagated artichoke, although there are possible emission problems with these fungicides. The poor quality of seed-propagated artichoke cannot be recommended for this crop, except in periods in which traditional produce is not found in the markets.

Pepper (transplantation in April)
The use of an anti-insects network (thermal cover) in a micro-tunnel, protecting the crop from early colonies of *F. occidentalis* resulted in excellent prevention from TSWV. The crop was in its final stages and most of the produce harvested when the disease started to seriously spread. The large populations of *Orius spp*. that were detected in all cases resulted in effective control of Frankiniella sp. The "California" type varieties appeared to be much less sensitive to this disease than the "Italian" pepper, variety Lamuyo. The virus CMV was detected every year although, as in the case of the TSWV, the disease started to spread seriously in the advanced growth stages. For the control of Oidium, periodical treatments with sulphur were sufficient.

Tomato (summer-autumn cycle)
The major disease problems in this crop were viruses. The use of resistant varieties to TSWV (Vodar and Bond), did not prevent serious infection of the produce with other viruses, mainly CMV and PVY, after having greatly reducing the yield, both in quality and in quantity. After the initial rains, symptoms of several diseases were detected (*Phytophthora parasitica, Alternaria spp* and *Cladosporium fulvum*), even when preventive treatments with copper were carried out. Curative products such as ***difenoconazole*** and ***azoxystrobin*** were used, which obtained effective control. Preventive treatments with sulphur against *Leveillula taurica* were usually effective; only in one case in which mycelium was detected, was the use of ***cyproconazole*** advisable.

Potato
The use of resistant varieties (Scort) to *Phytophora infestans* reduced the number of preventive treatments with copper needed in the integrated and organic systems. Symptoms of *alternariosis* were detected without observing any impact on the produce. The reduction of the copper treatments did not lead to larger infections of the previously mentioned diseases. Varieties resistant to mildew that are more commercially acceptable than the one used in the project should be determined.

Watermelon
The most important diseases for field-grown watermelon crops are Oidium (*Erysiphe spp.*) and *Fusarium oxisporum*. The latter is practically prevented by using grafts of pumpkin rootstock. In all cases, the crop appeared to be more resistant to Oidium in the initial crop stages because mycelium normally appeared after the first harvest. Preventive treatments with sulphur were sufficient for its control. The reduction of the number of sulphur treatments for the control of Oidium did not result in more infections of the disease. This strategy was used equally in organic farming as well as in integrated farming.

Fennel (transplantation in September)
In neither the organic nor the integrated systems, did this crop suffer from any disease. Treatments with copper for the prevention of *Septoria sp*. were only used in the first few years. In the last year, the disease did not occur, even though copper was not used.

Onion
The only disease detected in this crop was *Peronospora sp*., which usually appeared associated with *Stemphylium*. This strategy consisted of preventive treatments with copper and potassium phosphyte when the weather conditions were favourable for the development of the disease. An application of ***metalaxyl*** or ***azoxystrobin*** when initial symptoms occurred provided good results.

Celery
The preventive treatments with copper were normally sufficient for the control of *Septoria sp*. In one case, the disease occurred after being sufficiently treated with ***azoxystrobin***. On the other hand, *Sclerotinia sclerotiorum* always occurred in ES INT1. In the first year, a hailstorm caused scars in the plants that led to a general infection of the crop. In spite of the frequent treatments with ***procymidone***, produce quantity and quality were low. In the second year, a preventive application with ***azoxystrobin*** was used and the amount of irrigation water was reduced. Although the disease occurred that year, yield losses were insignificant.

Green bean
In ES INT3 and ES ORG, *Rhizoctonia solani* was always present in green bean. In the integrated system, ***procymidone*** was used the first year, combined with a reduction in irrigation. The results of this strategy were acceptable. In the second year, ***procymidone*** was substituted by the potassium permanganate in the irrigation water combined with an additional reduction of the water dosage. Again, the strategy sufficiently controlled the disease. In the organic system, sowing was substituted with planting seedlings because certain trials (Campos, IVIA) showed reduced crop susceptibility using seedlings. However, planting too deep resulted in the rotting of many plants. In ES INT2, diseases were not detected. Only one treatment with copper was necessary for scars caused by a hailstorm.

Sweet corn
There are no risks of diseases in this crop.

Table 5.4 is an overview of the most important diseases that occurred, as well as the different strategies used for their control.

5.3.3 Pest control strategies per crop
Only pests that are a danger for any of the crops produced are included in this section. It was remarkable that more than 85% of treatments against pests were for caterpillars. Table 5.5 gives an overview of the pest control strategies.

Table 5.4 Overview of disease control strategies for some crops in the integrated systems in ES INT1, ES INT2 and ES INT3

		Prevention							Need for control			Chemical control			
Crop	Disease	Crop rota-tion[1]	N-Ferti-lisation[2]	Seeds/plants[3]	Choice of variety[4]	Planting timing	Watering conditions	Incorp./ removal of residues[5]	Signal[6]	Damage threshold[7]	Guided control[8]	Physical control with insects nets	Seed plant treatment[9]	Preventive/ curative	Full field/row/spot[10]
Artichoke	*Leveillula taurica*	–	X	–	XX	–	–	–	XX	–	–	–	–	–	FF
	Rhizoctonia solani	XX	–	XX	X	–	X	–	–	–	X	–	X	–	R
Cauliflower	*Peronospora brasicae*	–	X	XX	X	–	–	–	X	–	–	–	–	XX	FF
	Xantomonas campestris	–	X	XX	–	X	–	–	X	–	–	–	–	XX	FF
Sweet corn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fennel	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Celery	*Septoria spp.*	–	X	X	–	X	–	–	XX	–	–	–	–	XX	FF
	Sclerotinia sclerotiorum	XX	X	–	–	X	XX	X	–	–	–	–	–	X	FF
Green bean	*BCMV*	X	X	XX	–	X	–	–	–	–	–	–	–	–	–
	BLRV	X	X	X	–	–	–	–	–	–	–	–	–	–	–
	Rhizoctonia solani	XX	X	X	–	–	XX	–	–	–	–	–	X	–	R
Pepper	*TSWV*	X	X	–	X			X	–	–	–	XX	–	–	–
	CMV	X	X	XX	XX	X	–	X	–	–	–	XX	X	–	–
	Leveillula taurica	–	X	X	–	–	–	X	XX	–	–	–	–	XX	FF
	Phytophtora capsici.	XX	X	–	–	–	XX	–	X	–	–	–	X	X	R/FF
Lettuce	*Big Vein*	X	X	XX	–	XX	–	–	–	–	–	–	–	–	–
	TSWV	X	X	XX	–	XX	–	–	–	–	–	–	–	–	–
	Bremia lactucae	–	–	X	X	XX	–	–	X	–	–	–	X	XX	FF
	Rhizoctonia solani	XX	–	X	–	X	XX	–	X	–	–	–	X	X	R
	Botrytis cinerea	XX	–	X	–	X	XX	–	X	–	–	–	X	X	R
	S. sclerotiourum	XX	–	X	–	X	XX	–	X	–	–	–	X	X	R
Onion	*Peronospora sp.*	–	X	X	–	–	–	–	–	–	–	–	–	XX	FF
	Stemphylium sp.	–	X	X	–	–	–	–	–	–	–	–	–	XX	FF
Potato	*Phytophtora infestans*	–	X	–	XX	–	–	–	XX	–	–	–	–	–	FF
	Alternaria solani	–	X	–	XX	–	–	–	XX	–	–	–	–	–	FF
Watermelon	*Erysiphe spp.*	–	–	–	–	–	–	–	XX	–	–	–	–	X	XX
	Fusarium oxisporum	XX	–	–	XX	–	X	–	–	–	–	–	–	–	–
	Verticillium spp.	XX	–	–	XX	–	X	–	–	–	–	–	–	–	–

All chemical control only applied in the integrated systems
XX = very effective or available
X = limited effective and/or manageable
\- = not relevant or possible

1. Is crop rotation effective as a preventive measure?
2. Is nitrogen limitation effective as a preventive measure?
3. Is infestation control or selection of seeds or plants effective?
4. Are there resistant or tolerant varieties available and used?
5. Is fast removal or incorporation of residues of the crop used?
6. Does control only takes place after detection of the disease and is this effective?
7. Is a damage threshold used?
8. Are there any guided control systems used?
9. Is planting or seed treatment used?
10. Are pesticides applied in the field: FF = Full field, R = row or band application, SP = spot-wise?
11. Is the applied dose lower than advice on packing?

Lettuce

In general, two key pests can be indicated: caterpillars and *N. ribisnigris*. Depending on the crop cycle, different problems occur: in the winter-spring cycle, the main problem is *N. ribisnigris*, and in second place are the caterpillars (*Plusias, Spodóptera spp.*). In autumn, the main problem are the caterpillars (mainly *Spodoptera spp.* and *Helicoverpa sp.*). In this cycle, aphids have a much lower incidence. In summer, pest problems are limited.

In the spring cycle, *Afidiidae* and other natural predators were never an effective control of *Nassonovia sp.*. In the organic system, its control was not possible in spite of the use of ***rotenone***. In the integrated system, periodic treatments were necessary to maintain control. It is very important to detect *N. ribisnigris* before the lettuce heads "close up" as control is much more difficult later on (colonies usually stay in the inner centre of the lettuce head). The products that provided the best results were ***deltamethrin*** + ***heptenophos*** and ***methyl pyrimiphos***. Poor results were obtained with ***pirimicarb***, ***azadiractin***, *Beauvearia sp.*, oil of the neem tree or ***rotenone***. The use of the resistant variety, Fortune, in iceberg lettuce was satisfactory. This could be an alternative for the organic system. The treatments against aphids in this cycle could also control caterpillars. In addition, ***Bacillus thuringiensis*** or ***azadiractin*** could be used.

In the autumn cycle, the treatments with ***Bacillus thuringiensis*** and ***azadiractin*** for the control of caterpillars were not effective. In this case, alternating pyrethroids mixed with mineral oil is advisable. The use of pyrethroids depends on the occurrence of the pests in the different zones and the timing of the treatments.

Finally, in the summer cycle (planting at the end of June), the treatments with ***Bacillus thuringiensis*** were sufficient for the control of caterpillars; the population of *N. ribisnigris* did not reach dangerous levels.

Agrotis spp. appeared with regular frequency in the initial stages of crop growth. However, the infection rarely reached more than 5% of the plants, the threshold value for treatment. The use of ***cypermethrin*** and ***chlorpyrifos-methyl*** applied in the irrigation water was an effective control. In addition, *Frankiniella sp.* appeared quite frequently, but without significant occurrence in the transmission of TSWV. There was no correlation between the level of *F. occidentalis* and the TSWV incidence.

Cauliflower and broccoli

In these crops, the major pests were aphids and caterpillars as well. In the case of aphids, the only species that reached dangerous levels was *Brevicoryne brassicae*. In all cases, the populations of afidiidae were very high and good control was possible. In some questionable cases, ***pirimicarb***, a very selective pesticide, was applied with very good results. It would be interesting to establish a threshold of treatment. In the organic system, the *afidiidae* effectively controlled *Brevicoryne* in all of the cases. Caterpillars were found more frequently in the plantings at the end of August than in the plantings from mid-September on. This fact became clearer in the case of *Hellula undalis*, which caused serious damage in the initial growth stages. For their control, ***chlorpyrifos*** was used and applied in the pot trays. Once established the crop in the field, periodical applications of alternating ***lambda-cyhalothrin*** and ***cypermethrin*** mixed with mineral oil were used. In the organic systems, periodical applications with ***azadiractin*** were effective (about 5% losses). After the crop's initial stages, the caterpillar species, Helicoverpa sp. and Spodoptera spp., never damaged the heads. Therefore, it was unnecessary to intervene in both organic and integrated systems.

Artichoke

The artichoke borer, *Gorthyna xanthenes*, can be considered as the principal pest in artichoke. However, when the crop cycle is limited to one year, the damage that this lepidopterous can cause in the harvest is insignificant. Other lepidopterous, such as *Agrotis sp., D. erinacella*, *Spodoptera spp.* and *Helicoverpa armigera*, can cause damage and a delay in production of the first stages of crop growth. The large populations of caterpillars that appear usually in this phase make periodic applications for their control necessary. The products most often used were ***lambda-cyhalothrin***, ***cypermethrin*** and ***chlorpyrifos*** in commercial bait. The application of the commercial bait, ***chlorpyrifos***, greatly reduces the amount of active ingredient per hectare, and the risk of toxicity to the applicator and natural predators. In the organic system, ***Bacillus thuringiensis*** was used in bait and ***azadiractin*** was also used, which obtained very good results.

The aphids, *A. phabae* and *Capitophorus eleagni*, can eventually become a problem, mainly in spring. In addition to the level of the pests, the decision to intervene depends on the destination of the produce. When artichoke is produced for the processing industry, the presence of aphids in the 'heads' does not depreciate the quality. The plants can resist high levels of pest, and natural predators can be very effective. Therefore, the threshold of treatment could be defined as the first appearance of sooty mould on plants. The natural predators detected with greater frequency were *afidiidae*, *coccinelidae* and parasite fungi (probably *E. Afidis*).

Treatments with soap in the organic and integrated systems, and localised treatments with ***pirimicarb*** in the integrated systems were also very effective.

Pepper (transplantation in April)

The large populations of *Orius spp.* that were detected provided very effective control of *Frankiniella sp.* The aphids, mainly *M. persicae*, were controlled by *afidiidae* and *coccinelidae*. *Phitoseids* were also frequently present in colonies of spider mites found. In addition, preventive treatments with sulphur provided good control. The caterpillars, preventively treated with ***Bacillus thuringiensis***, never caused a significant reduction in produce. In one case, white flies (*Trialeurodes sp.* and *Bemisia tabaci*)

caused in sooty mould on leaves, which was a risk for decline in produce. However, no treatment was carried out because the crop was in the final stages and parasitised white fly larvae were frequently detected.
In this strategy, it is important to determine the minimum frequency of treatments with ***Bacillus thuringiensis*** without affecting the produce. In this case, it was done every 10 or 15 days.

Tomato (cycle summer-autumn)
In the summer-autumn cycle of tomato, control with ***Bacillus thuringiensis*** and ***azadiractin*** was not effective due to the large amount of *Helicoverpa armígera* in this period. On the other hand, it is advisable not to use ***azadiractin*** after fruit setting because of the risk of damage to fruit. Then, pyrethroids can be alternated with ***chlorpyrifos-methyl***. White flies, *Bemisia tabaci* and *Trialeurodes vaporarium*, always developed into large populations. However, damage due to white flies was not recorded. The natural predators, *Macrolophus spp.* and *Dyciphus tamanii*, were frequently detected in large populations. The use of ***buprofezin***, ***teflubenzuron*** and ***lambda-cyhalothrin*** was never efficient. The russet mite was controlled with sulphur treatments, which started after the detection of the initial symptoms. Aphids never reached dangerous levels.

Potato
The major pest in this crop was *Agriotes spp*. To determine the need for treatment, food traps were set. If individuals were found, ***cypermethrin*** and ***chlorpyrifos-methyl*** were used, both applied in the trickle irrigation (one or two treatments per crop were sufficient for effective control). The food used in the traps consisted of a mixture of wheat and wet maize, which had better results than pre-germinated maize. The reliability of the traps was questionable, because in some cases, damaged tubers were found without detecting individuals in the traps.
The treatments for *Leptinotarsa sp.* were normally carried out to protect nearby crops (tomato and eggplant). Because the pest appeared in the last growth stages, production losses because of this pest were minimal. The use of ***lambda-cyhalothrin*** and ***teflubenzuron*** in integrated systems and ***Bacillus thuringiensis*** (var. Kurstacki, strain EG2424) in the organic system were effective in all cases. A damage threshold, dependent on the stage of growth, needs to be developed.

Watermelon (transplantations in April and May)
In watermelon, the major pests were aphids (*A. gossypii*), always in early April plantings and the maximum levels detected at the end of April or beginning of May. In these cases, it was necessary to control the pest with ***acephate***, ***lambda-cyhalothrin*** or ***imidacloprid***, this last pesticide applied with irrigation water. No applications were necessary in plantings after mid-May because large levels of parasitism were detected in the first colonies of aphids infecting the crop. If the crop is maintained until the end of August, a second infestation of aphids can occur. In the organic system, the use of a detergent or ***rotenone*** was not effective enough against aphids. The pest caused considerable damage in plants; however, the planting in mid-May did not have aphid problems.
Reduced quality caused by ***Spodoptera*** sp. depends on the destination of the produce. In produce for the national market, this pest does not need to be treated. For export, very good results have been obtained with periodical applications of ground carob without mixing in any type of pesticide. In addition, ***Bacillus thuringiensis***, granulated bait of ***chlorpyrifos*** and ***lambda-cyhalothrin*** were used. The crop's susceptibility to attacks of spider mites was increased after the maximum levels of aphids were found. The preventive treatments with sulphur resulted in good control both in organic and integrated systems. Large populations of phytoseids were also quite frequently detected.

Fennel (transplantation in September)
Aphids (*A. phabae*) and caterpillars (*Agrotis sp.* and *Spodoptera spp.*) were detected frequently in fennel. In the beginning, a decision was made to control these insects, using in the integrated system ***lambda-cyhalothrin*** for aphids and granulated bait of ***chlorpyrifos*** for caterpillars. In the organic system, bait with ***Bacillus thuringiensis*** was used to control caterpillars, and aphids were not controlled. In the last year of the project, no control of aphids and minimum control with ***Bacillus thuringiensis*** were carried out because it appeared that damage by both pests was not significant. There was no decrease in the produce due to pests or diseases. Possibly, the treatments for caterpillars could be omitted completely as well.

Onion
The control of trips in the crop's initial phases was eliminated from the strategy as no losses in the produce in any of the cycles were observed (harvest at maturity of the bulbs). The products used at the beginning were ***naled***, ***isophenphos*** and mineral oil, with non-satisfactory results. In ES INT3 and ES ORG, a rare and unexpected problem appeared that caused great losses in produce. The pest has not been identified yet; it was probably *Delia platura*, which is capable of living in the previous crop's residues. Holes made in the young plants caused plant death or serious alterations in their development. In the integrated system, ***cyromazine*** was applied in the irrigation water, and ***fenvalerate*** and ***diazinon*** were sprayed. The results were not completely satisfactory in any of the cases. The same occurred in the organic system with the use of ***azadiractin***. The treatment by immersion in transplantation with ***isophenphos*** or ***azadiractin*** is the alternative proposed for a more effective control.

Celery (transplantations in September)
The caterpillars, mainly *Spodoptera spp*, but also *Agrotis pp.*, *H. armigera* and *Plusia spp.*, are the key pests in cel-

Table 5.5 Overview of the pest control strategies for integrated and organic systems of Paiporta (ES INT3 and ES ORG)

		Prevention					Need for control			Chemical control		
Crop	Pest	Crop rotation[1]	N-Fertilisation[2]	Selection seeds/ plants[3]	Choice of variety[4]	Crop cycle[11]	Signal[6]	Damage threshold[7]	Guided control[8]	Crop cover (physical control)	Seed/plant treatment[9]	Full field/row/spot[10]
Artichoke	*Capitoforus eleagni*	–	X	–	–	–	XX	–	–	–	–	SP
	Depresaria erinacela	–	–	–	–	–	XX	–	–	–	–	FF
	Gorthyna xantenes	X	–	X	–	XX	–	X	X	–	–	FF
	Spodoptera spp.	–	–	–	–	–	XX	–	–	–	–	R/FF
Cauliflower	*Myzus persicae*	X	X	–	–	–	XX	–	–	–	–	FF
	Brevicoryne brassicae	X	X	–	–	–	XX	X	–	–	–	FF
	Helix spp.	–	–	–	–	–	XX	–	–	–	–	FF
	Heilula iundalis	–	–	–	–	XX	X	–	–	–	XX	FF
	Spodoptera exigua	–	–	–	–		XX	–	–	–	–	FF
Fennel	*Agrotis sp.*	–	–	–	–	–	XX	–	–	–	–	FF/–
	Aphis fabae	X	X	–	–	–	XX	–	–	–	–	SP/–
	Spodoptera spp.	–	–	–	–	–	XX	–	–	–	–	FF/–
Green bean	*Aphis fabae*	X	X	–	–	X	XX	–	–	–	–	–
	Helicoverpa armigera	–	–	–	–	–	XX	–	–	–	–	FF/–
	Helix spp.	–	–	–	–	–	XX	–	–	–	–	FF/–
	Tetranychus spp.	X	X	–	–	X	X	–	–	–	–	FF/–
Lettuce	*Plusia spp.*	–	–	–	–	X	XX	X	–	–	X	FF
	Spodoptera spp.	–	–	–	–	X	XX	X	–	–	X	FF
	Myzus persicae	X	X	–	–	X	XX	–	–	–	–	–
	Nasonovia ribisnigris	–	X	–	X	XX	X	–	–	–	–	FF
Onion	*Delia sp.*	X	–	X	–	–	–	X	–	–	XX	R
	Thrips tabaci	–	–	X	–	XX	X	–	–	–	–	–
Potato	*Agriotes sp.*	–	–	X	–	–	–	XX	–	–	–	irrigation
	Leptinotarsa decemlineata	–	–	–	–	X	XX	–	–	–	–	FF
Watermelon	*Aphis gossipii*	X	X	–	–	XX	XX	–	–	X	–	SP/FF
	Spodoptera exigua	–	–	–	–	–	X	–	–	–	–	FF/–
	Tetranychus spp.	X	X	–	–	–	X	–	–	–	–	FF

Chemical control in the organic system is done with bio-pesticides and mineral compounds

XX = very effective or available

X = limited effective and/or manageable

\- = not relevant or possible

1. Is crop rotation effective as a preventive measure?
2. Is nitrogen limitation effective as a preventive measure?
3. Is infestation control or selection of seeds or plants effective?
4. Are there resistant or tolerant varieties available and used?
5. Is fast removal or incorporation of residues of the crop used?
6. Does control only takes place after detection of the disease and is this effective?
7. Is a damage threshold used?
8. Are there any guided control systems used?
9. Is plantling or seed treatment used?
10. Are pesticides applied in the field: FF = fulfield, R = row or band application, SP = spot-wise?
11. Can the pest be avoided by changing the growing cycle of the crop?

ery. The large populations that currently appear in this cycle during the initial stages of plant growth make periodical applications necessary. As the crop develops, their control is increasingly difficult because the larvae are located in the central part of the plant and the exterior leaves make pesticide use less effective. The main change in the strategy to control this pest has been the selection of other pesticides; ***trichlorfon*** has been eliminated and instead mixes of pyrethroids with mineral oil, alternated with ***azadiractin*** are used. The use of ***chlorpyrifos*** in pre-transplantation (in the pan pots) protects the crop in the first stages of plant growth and reduces the effect of this pesticide on the environment. The incidence of the pests is different depending on the zones. The treatments for caterpillars can serve to control *Lirimyza trifolii*. In every case, high levels of parasitism (mainly *Diglyphus issaea*) were always detected. ***Azadiractin*** appeared to be highly effective. On the other hand, damage to leaves in the initial stages of plant growth did not affect the final quality of the produce because the levels of the pests decrease considerably during the winter period. The aphid *A. gossypii* only reached dangerous levels in one case around harvest time in February. There was no intervention and no decrease in the produce was measured.

Green bean
Although *A. phabae* reached dangerous levels in some cases, with some serious spots, it was not necessary to intervene because the natural predators were effective. Concerning caterpillars, several species were detected, but *H. armígera* was the only one that had a slight impact upon the produce; the treatments with ***Bacillus thuringiensis*** were sufficient for its control. The preventive treatment with sulphur was effective in preventing damage caused by spider mites. In addition, individuals of phytoseids in the colonies of tetraniquids were detected frequently. There was no difference in the management of pests between the integrated and organic systems.

Sweet corn
The weekly treatments with ***Bacillus thuringiensis*** started after lepidopterous excrement was found. In the first year, *Trichogramma evanescens* was released and synthetic pesticides were not necessary to control *Ostrinia sp.* and *H. armígera.* However, in the two following years (there were no releases), the use of pyrethroids was necessary when larvae in more advanced stages was found. These treatments could cause unbalance in the ecological niches of aphids and spider mites, resulting in risky population levels in both pests.
Only once, damage caused by *Agriotes spp.* was detected directly after emergence. ***Chlorpyrifos-methyl*** was applied in the irrigation water with good results. The substitution of ***chlorpyrifos-methyl*** by ***cypermethrin*** reduced the environmental impact.

5.4 Testing and Improving

5.4.1 Introduction
False sowings were difficult in the systems because the fields could not be made entirely wet with the drip irrigation system used. The best time to carry out false sowings is in the rainy season. Then, expensive irrigation water is saved as well.

The timing for mechanical and manual weeding was sometimes not effective. This increased the hours of manual labour needed considerably. Probably, the farmer managers did not make this task the priority that it needed to be. Due to the poor timing, the risk that weeds seeded was higher than when no herbicides were used. This led to an increase in the weed infestation level of the fields.

Mechanical weed control was difficult to combine with trickle irrigation as weeds grew mainly in the area of irrigation, or the crop rows, where the use of most mechanical weeding equipment is limited. In general, manual weeding was necessary in all crops (see Weed Control tables).

The localised use of herbicides (spot-wise or band spray) was effective when the level of weeds was medium to low.

The use of tolerant or resistant cultivars to control diseases was satisfactory only in some cases. Physical barriers, adapting the crop cycles to the less sensitive periods and proper management of tasks were other measures that provided better results in the Spanish systems.

It was not possible to evaluate the effects of crop rotations on (soil-born) pests and diseases due to the limited length of the project. However, the interaction between crops was positive in some cases due to crop rotation and natural predators, which could pass easily on to the next crops. In addition, a survey was carried out to determine the presence of the different species of natural predators in the hedgerows. The most common natural predators found were:
- *Machrolophus sp.* and *Dyciphus sp.* in *Inula viscosa,*
- *Orius spp.* in *Nerium oleander,*
- *Aphidiidae* and *Eulófidae* in *Mioporum pictum, Coronilla sp., Medicago sp.* and *Doycnium sp.*

Biological pesticides, which are less aggressive to the environment and the plants, are advised to be used as a preventive measure in certain cases. At the beginning of the project, a general strategy based on biological control was designed for the control of caterpillars. Pesticides such as ***Bacillus thuringiensis*** and ***azadiractin***, and sulphur as general repellent of pests were used. The first two pesticides resulted in effective control (for details, see paragraph 5.3), whereas sulphur was only effective in the control of spider mites. The use of a thermal blanket provided very good results in pepper, by retarding and reducing the colonisation by *Frankiniella sp*. However, thermal blankets did not stop the infestation of aphids in early watermelon.

5.4.2 Control strategies, quality production, costs and manual weeding

The objective to grow good quality produce was tested with the quantity (QNP) and quality of production (QLP) parameters. Target values for these parameters were established, using as a reference the optimum production from the different areas according to criteria of Good Agricultural Practices (GAP). QNP and QLP were calculated by dividing the actual yield and quality by the target yield and quality (when actual yield is equal to the target yield the QNP = 1). The target levels in the organic system were estimated separately based on optimal production under organic conditions. In the conventional system, production is estimated on average at 80% of the optimum production levels (QNP and QLP are about 0.8).

Several factors can cause loss of produce (Table 5.6). It is estimated that pests and diseases caused approximately 50% of the losses in the integrated systems and 60% in the organic system. Several other causes of losses were weather conditions, physiological disorders, incorrect crop management and poor conditions in the markets. The mean values of QNP and QLP were, in all integrated systems, very close or higher than in conventional production, although there were years in which QNP and QLP were very low. The means of QNP and QLP in the integrated systems were lower than the QNP and QLP in the organic system (Figure 5.1 to 5.4, QNP 0.89 versus 0.98 and QLP 0.90 versus 0.96, with GAP integrated used as target). The comparison between integrated and organic systems can only be done in detail between ES INT3 and ES ORG because these systems were located on the same farm with the same rotation and other conditions. The yields of the ES ORG were about 10% lower than the yield of ES INT3.

In Pilar de la Horadada (ES INT1), aphids in watermelon and caterpillars in sweet corn caused large losses in 2000. However, the major causes of losses were the market conditions, because of an excessive supply of the iceberg lettuce and little gem in spring (losses of 80% and 73%, respectively). *A. Gossypii* caused a decrease in watermelon production of 38% due to lack of an opportunity to treat this pest. The losses in sweet corn caused by *Ostrinia sp.* and *Helicoverpa sp.* were about 17%. In this case, poor application probably caused a reduction in effective control. In general, the main phytopathologic problem in ES INT1 was caterpillars, mainly in the end of summer and autumn, ***Bacillus thuringiensis*** or ***azadiractin*** applications very often not effective controls in these periods with very large lepidoptera populations.

In Benicarló, ES INT2, 2000 was a bad year, due to diseases and weather conditions. The spring lettuce crop was lost completely, due to a serious infection of mildew. A better choice of fungicide as well as better opportunities to carry out the treatments could have saved the crop. In addition, PVY and CMV appeared especially aggressive this year in tomato crops with losses of 60% in quantity and 95% in quality. Verticilium seriously damaged artichoke, although it is possible that the exhaustion of the soil intensified the infection (53% quantity loss). A suitable rotation can probably greatly help to reduce infections. Green bean was damaged by a windstorm during the harvest, causing losses of 60%.

The best results were obtained in Paiporta, which had high values of QNP in 2000 (1.32 in ES INT3 and 1.38 in ES ORG). The worst year in these systems was 1999 due to pests, incorrect management in certain crops and weather conditions. In 1999, a hailstorm caused damage to 30% of the green beans. The planting of summer lettuce was done too deep, which caused all produce to be lost. Onion was not harvested as well because of a severe attack by Delia sp.. Finally, a loss of 25% of the spring lettuce was caused by tip burn.

In the organic system, it was impossible to control Nassonovia sp. in spring lettuce, resulting in a total loss of all produce.

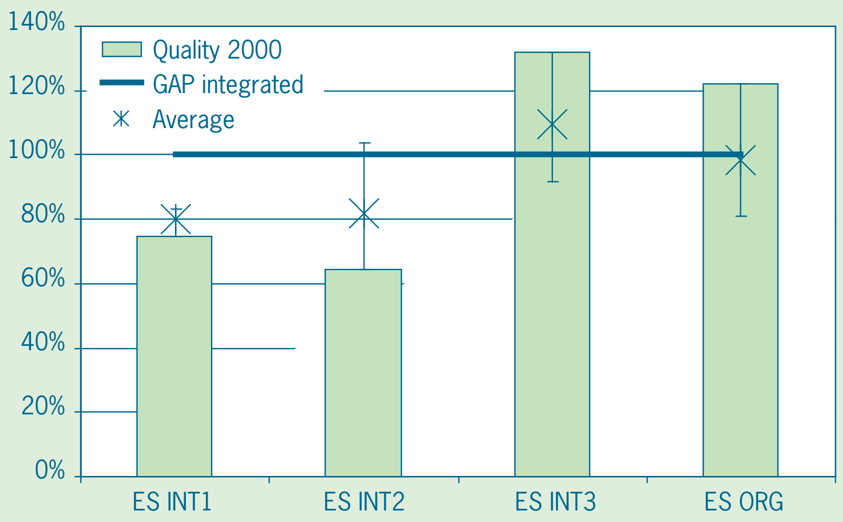

Figure 5.1 Comparison of relative production to GAP integrated

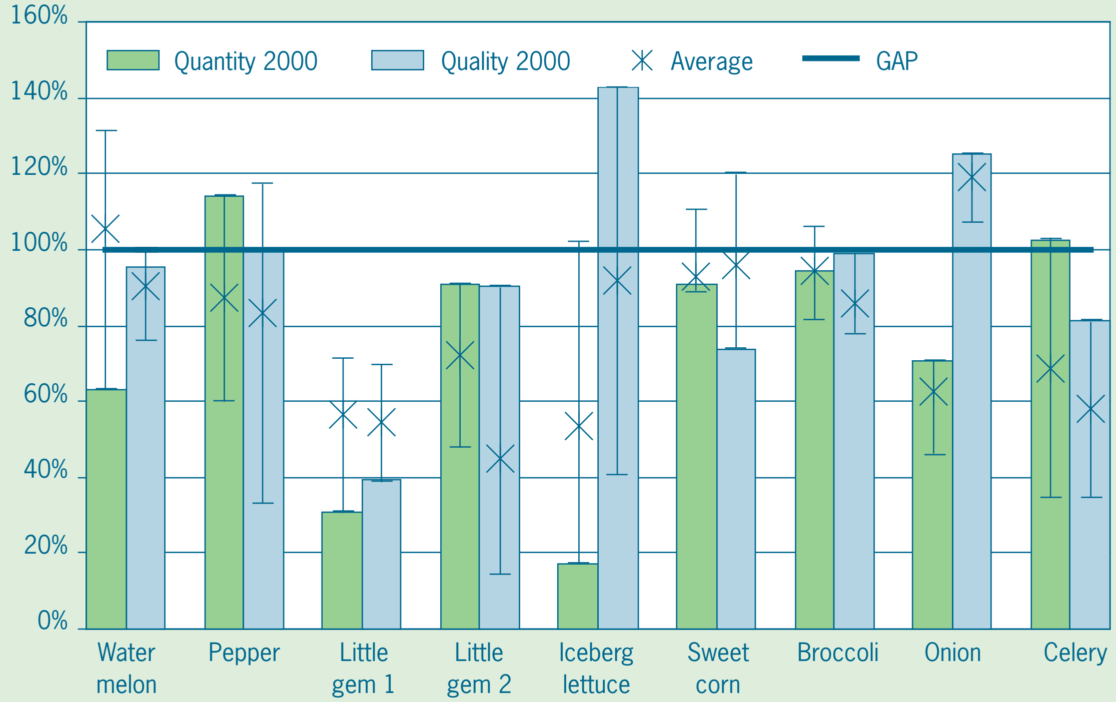

Figure 5.2 Quantity and quality production in system ES INT1 compared to GAP

Limiting herbicide use led, in some cases, to an increase of the weed infestation level in the fields with medium infestation levels (ES INT1and ES INT3). In ES INT2, where infestation levels were lower, the more restricted use of herbicides did not mean a significant increase of manual weeding hours in comparison to the conventional

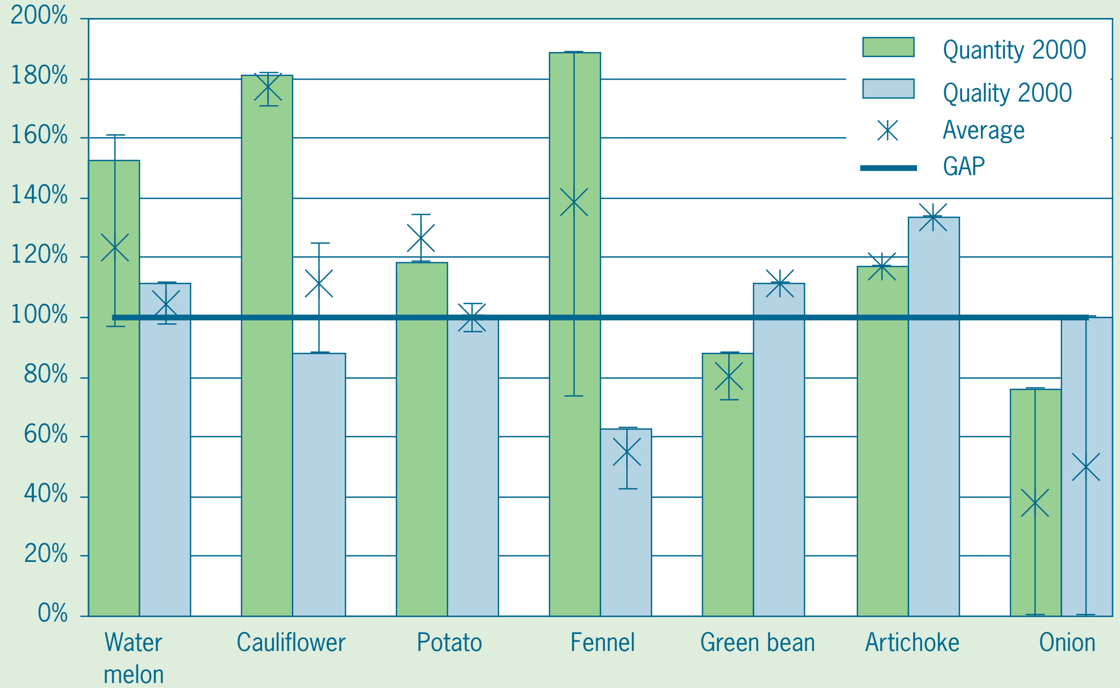

Figure 5.3 Quantity and quality production in system ES INT3 compared to GAP (crops removed from the rotation are not included)

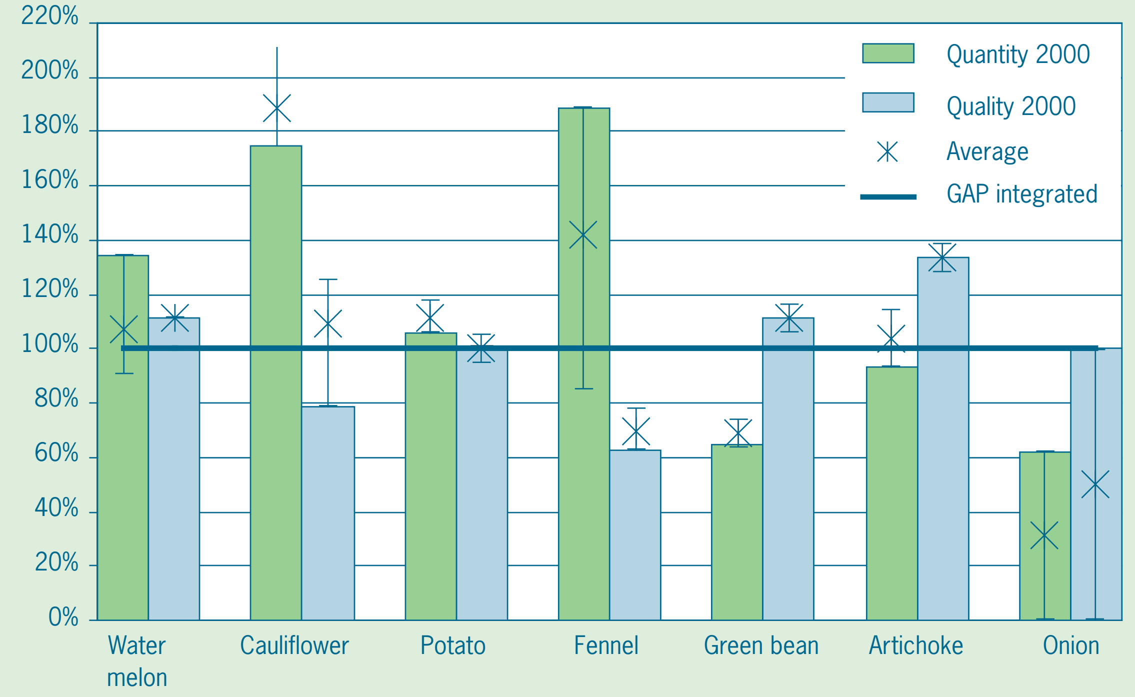

Figure 5.4 Quantity and quality production (2000) in ES ORG compared to GAP (crops removed from the rotation are not included)

systems (see graph 5.5). In ES INT2, it was possible to grow several crops without using herbicides and with a moderate number of hours of manual weeding (lettuce, green bean, cauliflower and watermelon). This is partially due to the correct use of the walking tractor. On the other hand, the lack of proper machinery in ES INT1 meant a dramatic increase in hours of manual weeding. In Figure 5.5, the hours of manual weeding (HHW) are shown per system and per crop (see Chapter 5.2, 'Weed Control'). Stable and satisfactory strategies were obtained in tomato, watermelon, celery, sweet corn, potato, cauliflower and broccoli. Strategies need certain

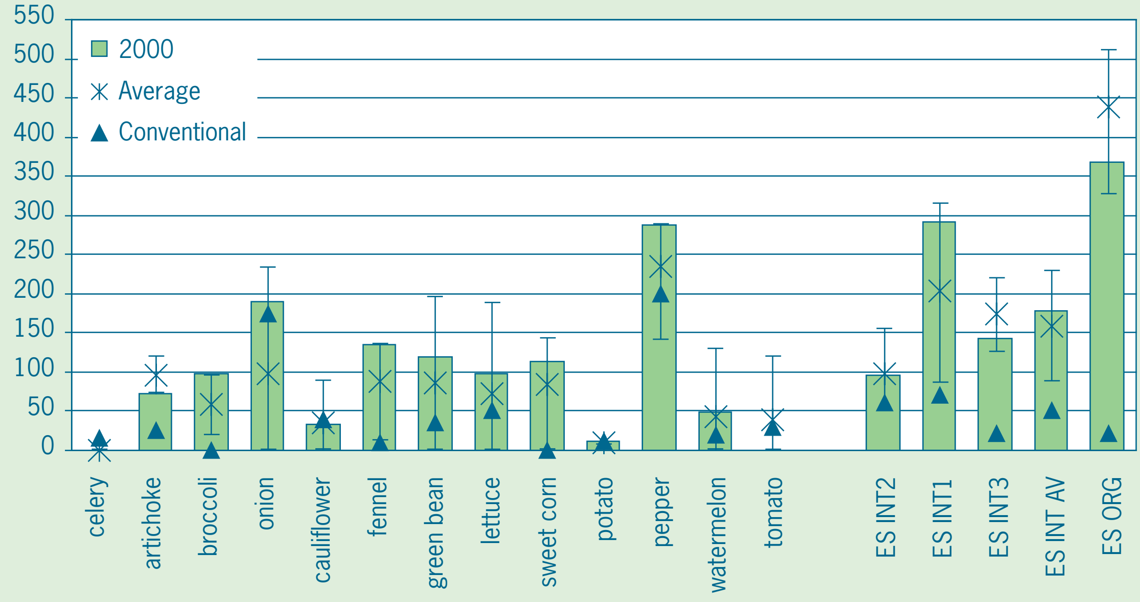

Figure 5.5 Hours of manual weeding per crop and per system in 2000 and average

Table 5.6 Pest and disease causes of shortfall in quality production

System	Crop	Shortfall caused by	Disease/ pest cause	Shortfall in strategy*
ES INT1	Autumn lettuce	QNP, damage in heads (not marketable)	Caterpillars	Spraying frequency and choice of insecticide.
ES INT1	Watermelon	QNP, damage in plants and decrease in yield	Aphids	Spraying frequency
ES INT1	Pepper	QLP, spotted fruits	TSWV, CMV	Availability of resistant variety
ES INT1	Sweet corn	QNP, QLP damage of corncobs	*Ostrinia, Helicoverpa*	Inadequate application technique, pesticide choice, application frequency (?)
ES INT2	Spring lettuce	QNP, downy mildew	Bremia lactucae	Application frequency, Fungicide choice (?) Availability of resistant variety
ES INT2	Tomato	QNP, decrease in yield, damaged fruits. QLP, bulky fruits	PVY, CMV	(?)
ES INT2, ES INT3	Artichoke	QNP, missed stumps and death of plants	*Verticilium, Rhizoctonia, soil exhaustion*	Pesticides not effective enough. Crop rotation needed
ES INT3	Onion	QNP, death of seedlingsQLP, decreased vigourof plants and delay of harvest	*Delia sp.*	Preventive applications needed and removing crop residues of previous crop
ES INT3	Autumn lettuce	QNP, no marketable	TSWV (viruses)	Sensitive period of planting, availability of headsresistant variety
ES ORG	Artichoke	QNP, death of stumps or decrease in vigour plants	*Rhizoctonia, Verticilium*	No efficient control available (testing thermal disinfecting)
ES ORG	Onion	QNP, death of seedlings QLP, decreased vigour of plants and delay of	*Delia sp.*	Preventive applications needed and removing harvestcrop residues of previous crop
ES ORG	Autumn lettuce	QNP, no marketable heads	TSWV (viruses)	Sensitive period of planting, availability of resistant variety
ES ORG	Spring lettuce	QNP, abundant presence in heads	*Nassonovia ribisnigris*	No effective insecticide and resistant varieties not
ES ORG	Early watermelon	QNP, damage in plants QLP, fruits spotted by honeydew	*Aphids*	No efficient control

adjustments in lettuce, green bean and artichoke. Strategies in onion, pepper and fennel need major modifications. The poor results obtained per system were due mainly to several attempts to reduce the use of herbicides that finally did not succeed.

5.4.3 Pesticide use, emission and damage risks

The change in choice of pesticides greatly decreased the emissions to the environment (Table 5.7). The different amount of spraying solution used in the applications in the different systems brings is a consequence of the same treatment causing different environmental effects that depend on the farming area. This is because the dosage for insecticides and fungicides is based on a concentration instead of an amount per hectare. The average amount of spraying solution used in Benicarló in developed stages of the crop is 1000 l ha^{-1}; in Paiporta (ES INT3 and ES ORG) this average is 1500 l ha^{-1} and in Pilar (ES INT1), 2000 l ha^{-1}. In addition, the use of pesticides was higher in ES INT1 because of a higher pressure of pests and diseases in the area, as well as more crops were included in the rotation.

From the beginning, the decision was made to remove certain pesticides (***paraquat*** and dithiocarbamates) from the strategies, for either environmental reasons or residue problems on the produce. The following active ingredients have been substituted because of their high environmental effect and/or low efficacy: ***trichlorfon***, ***procymidone***, ***metribuzin***, ***propachlor***, ***cyromazine***, ***endosulfan***, ***fenvalerate***, ***linuron***, ***metabenzotiazuron***, ***methomyl***, ***naled***, ***pendimethalin***, ***terbuthylazine*** and ***terbutryn***. The use of other compunds was restricted due to environmental reasons (***pyrimiphos-methyl***, ***chlorpyrifos*** and ***chlorpyrifos-methyl***).

In general, the substitution of the organophosphates by pyretroids, the latter ones with much lower concentration of active ingredients, has been the main reason for the reduction in active ingredient use (PESTAS-Synth, an average reduction of 75%). The results in the integrated systems were always below the estimated use in conventional systems and the target value was reached in all cases. In addition, ***Bacillus thuringiensis***, ***azadiractin***, copper and sulphur, the most important active ingredients used were ***azoxystrobin***, ***glufosinate***, ***oxyfluorfen***, ***metobromuron***, ***prometryn*** and ***chlorpyrifos***.

In the organic system ES ORG, the obtained PESTAS-Synth was always lower than in the integrated systems (0.3 kg ha^{-1}in 1999 and 0.22 kg ha^{-1} en 2000). The most important active ingredients used were ***azadiractin***, neem oil, ***metaldehyde*** and ***rotenone***.

The reduction obtained in the potential emission of pesticides to the air (EEP air) was even higher than in PESTAS-Synth (on average 90%). In the integrated systems, the value for EEP air was still higher than the target value in 1999, and in ES INT1, it was also above the estimated value for conventional systems. In ES INT1, the active ingredients with the highest exposure to the air were (in decreasing order of importance): ***pyrimiphos-methyl***, ***procymidone***, ***propachlor*** and ***trichlorfon***. In ES INT2, the pesticides that contributed the most to EEP air values were ***chlorthal*** + ***propachlor***, neem oil, ***chlorpyrifos***, ***naled*** and ***trichlorfon***. In ES INT3, the list was ***pendimethalin***, ***trichlorfon***, ***chlorpyrifos-methyl***, ***procymidone*** and ***pirimicarb***.

In 2000, ***procymidone***, ***pendimethalin***, ***chlorthal***, ***propachlo***r, ***trichlorfon*** and ***naled*** were removed from the strategies, and the use of ***chlorpyrifos-methyl*** and chlorpyrifos were restricted. In spite of this, the active ingredients with a high EEP air value were ***chlorpyrifos***, ***chlorpyrifos-methyl***, ***deltamethrin*** + ***heptenophos*** and ***azadiractin*** in that year. The differences between systems were mainly due to different dosages per

Table 5.7 Values obtained that are related to pesticide use and emissions

	Number of applications no ha^{-1}	Active ingredient input kg ha^{-1}	EEP air kg ha^{-1}	EEP groundwater ppb	EEP soil kg days ha^{-1}	Copper input kg ha^{-1}
ES INT1						
Conventional 2000	34	26.8	3.59	28.25	1269	5.2
Actual 1999	20	7.5	2.76	141.39	617	0.4
Actual 2000	19	2.7	0.35	0.69	223	0.2
VEGINECO target	-	13.4	1.80	0.50	381	1.6
% reduction 2000 - conventional	43	90	90	98	82	97
ES INT2						
Conventional 2000	18	7.8	1.46	21.72	783	1.1
Actual 1999	17	5.2	2.21	110.80	665	1.1
Actual 2000	18	1.4	0.20	0.02	120	0.5
VEGINECO target	-	3.9	0.44	0.50	235	0.3
% reduction 2000 - conventional	0	82	86	100	85	55

Table 5.8 Main differences in herbicide inputs between conventional and actual VEGINECO

Crop	Application type	Conventional pesticide	Pesticide 2000	Difference in strategy
Lettuce	Full field, pre-planting	***pendimethalin***	***propyzamide***	Herbicide selection
Lettuce	Full field, pre-planting	***propyzamide***	-	Complete mechanical control, Mulching
Artichoke	Full field pre-planting	***linuron***	-	No herbicide in full field applications
Artichoke	Located in crop	***paraquat***	***oxyfluorfen***	Herbicide selection
Potato	Full field	***linuron***	-	Complete mechanical control
Fennel	Pre-planting full field	***pendimethalin***	***glufosinate***	Contact herbicide (located)
Sweet corn	Pre-planting, full field	***atrazine*** + ***metolachlor***	***MCPA***	No residual herbicide (located), mulching
Tomato	Full field in crop	***metribuzin***	***glufosinate***	No residual herbicide (located application) Mechanical control (low infestation level)
Green bean	Full field, pre-planting	***chlorthal*** + ***propachlor***	***glufosinate***	No residual herbicide (located application) Mechanical control (low infestation level)

hectare, different phyto-sanitary situations, and the use of different active ingredients for different crops.
In the organic system in Paiporta (ES ORG), the active ingredients, responsible for environmental impact on the air, were neem oil, ***azadiractin*** and ***rotenone*** in 1999. In 2000, ***rotenone*** was removed from the strategies due to its reduced effectiveness on aphids in watermelon.

In groundwater, the use of certain active ingredients greatly exceeded the target value in 1999, which was even higher than those estimated for conventional systems. The active ingredients responsible were ***procymidone***, ***propachlor*** and ***propachlor*** + ***chlorthal***. All of these ingredients were substituted in the crop strategies in the year 2000. In 2000, an average reduction of 87% was achieved for this parameter. In ES INT1, the actual value was slightly higher than the target value (0.69 versus 0.5 ppb). In ES INT2, the target value was obtained. In ES INT3, the use of ***cyromazine*** in onion caused the target value to be exceeded (32.94 versus 0.5 ppb). ***Cyromazine*** was removed for future strategies. ***Chlorpyrifos-methyl*** could cause values of EEP groundwater that were too high, and one application in ES INT3 resulted in an EEP groundwater value of 4.2 ppb. It is advisable to restrict or substitute this pesticide in future.

In organic farming, the only active ingredient that had an impact on the groundwater was ***metaldehyde***, although the actual value was far below the target value (0.01 versus 0.5 ppb).

Emissions from pesticides in the soil were reduced on average by 63%, which was the target value in all systems in the year 2000. The active ingredients used, with a high potential emission to the soil (EEP soil), were in decreasing order: ***propachlor*** + ***chlorthal***, ***chlorpyrifos***, ***azoxystrobin***, ***trichlorfon***, ***pirimicarb***, ***pencycuron***, ***pyrimiphos-methyl***, ***pendimethalin*** and ***benomyl*** in 1999. In 2000, only ***pirimicarb***, ***pencycuron*** and ***azoxystrobin*** were kept in the crop strategies, the use of ***chlorpyrifos*** and ***pyrimiphos-methyl*** was restricted.

In 2000, active ingredients with a potential emission to the soil were ***fueron***, ***azoxystrobin*** and ***cyromazine***. The latter will not be included in future strategies because it is not effective for *Delia sp.* control in onions. New alternatives, with a lower impact on soils, are needed instead of ***azoxystrobin*** for the control of certain pathogens. In ES ORG, the active ingredient with a potential emission to the soil was ***metaldehyde***. The values obtained for this parameter in this system were 0.0 and 3 kg days ha^{-1} in 1999 and 2000, respectively.

In organic farming, the use of copper as fungicide is being actively discussed because of its impact on the environment. As it is used as a substitute for synthetic fungicides that often have a greater impact on the environment, it is difficult to replace this compound. The use of preventive measures such as resistant or tolerant varieties and the use of potassium phosphyte in integrated systems are alternatives to reduce the use of copper. These alternatives have already reduced the use by 50% (PESTAS-Cu) in one year. This resulted in use below the target value in the systems ES INT1 and ES INT2 and slightly above the target value in ES INT3 and ES ORG.

In general, the impact on the environment in the integrat-

Table 5.9 Main differences in fungicide inputs between conventional and actual VEGINECO 2000

Crop	Disease	Conventional fungicide	Fungicide 2000	Difference in strategy
Potato	Late blight	***metalaxyl + mancozeb***	-	Use of resistant cultivars
Lettuce	Downy mildew	***metalaxyl + mancozeb***	***azoxystrobin***	Removing ditiocarbamates, lower frequency
		cymoxanil + Folpet copper	***benalaxyl*** + copper phosphyte	Preventive use
	Botrytis, Sclerotinia	***iprodione***	***azoxystrobin***	Lower frequency, reduction of water irrigation is effective
		cyprodinil + fludioxonil	-	
Watermelon	Powdery mildew	***pyrazophos*** ***pyrifenox*** ***myclobutanil***	sulphur sulphur sulphur	Good control possible with sulphur
Celery	*Sclerotinia*	***procymidone***	***azoxystrobin***	Lower frequency, reduction of water irrigation is effective, lower environmental emission (air and groundwater)
Onion	Downy Mildew	***metalaxyl + mancozeb***	***azoxystrobin***	Removing ditiocarbamates
Artichoke	*Ascochytia*	***carbendazim*** ***thiophanate-methyl*** + ***mancozeb***	- -	Abiotic origin of the disease, not necessary application
	Powdery mildew	***triadimenol***	sulphur	Good control with sulphur
Cauliflower and broccoli	Downy Mildew	***metalaxyl + mancozeb***	***metalaxyl*** + copper	Removing ditiocarbamates, lower frequency, preventive applications with copper
Pepper	*Phytophthora sp.*	***benomyl*** copper oxychinolate	-	No problems in VEGINECO crops (good irrigation management is necessary)

ed systems was mainly due to insecticides, followed by fungicides or herbicides, but the order depends on the parameters. In the organic system, the most important impact on the environment was caused by a molluscicide. EEP air in the organic system was affected by insecticides (75%). The main differences in strategy differences and pesticide use are summarised in Tables 5.8 to 5.10.

Table 5.10 Main differences in insecticide inputs between conventional and actual VEGINECO 2000

Crop	Pest	Conventional pesticide	Pesticide 2000	Difference in strategy
Potato	Aphids	***lambda-cyhalothrin***	-	Sufficient control by natural predators
	Leptinotarsa	***lambda-cyhalothrin***	***(lambda-cyhalothrin)***	To protect neighbouring crops (good control with ***bacillus thuringiensis*** in the organic system)
Fennel	Aphids	***lambda-cyhalothrin***		Sufficient control by natural predators
	Caterpillars	***chlorpyrifos***	***bacillus thuringiensis***	Sufficient control with ***bacillus thuringiensis***
Lettuce	*N. ribisnigris*	***imidacloprid***	***deltamethrin*** + ***heptenophos***	Reduced environmental emissions (soil and ground-water)
	Caterpillars	***endosulfan***	***cypermethrin*** + mineral oil	Reduced environmental emissions, less toxic for appliers
		lufenuron	***lambda-cyhalothrin***+ mineral oil	
		methomyl	***bacillus thuringiensis***	
Artichoke	Caterpillars	***chlorpyrifos***	***azadiractin*** + mineral oil	Reduced environmental emissions
		fenitrothion	***lambda-cyhalothrin*** + mineral oil	
	Aphids	***pirimicarb+endosulfan***	soap	Sufficient control with soap
Green bean	Spider mite	***fenbutestan***	sulphur	Preventive applications, sufficient control by natural predators, reduced emissions.
	Aphids + White fly	***imidacloprid***	-	Close observation, sufficient control by natural predators
	Aphids + Caterpillars	***deltamethrin*** + ***heptenophos***	bacillus thuringiensis	Sufficient control with ***bacillus thuringiensis***, insignificant damage to yield
	Caterpillars	***lambda-cyhalothrin***	-	
Watermelon	Aphids	***propoxur***	-	No applications needed when planted late (mid-May)
		fluvalinate	(***lambda-cyhalothrin***)	
		pirimicarb + ***endosulfan***	-	
	Spider mite	***hexitiazox*** + ***dicofol***	sulphur	Preventive applications, natural predators frequently detected
		tebufenpyrad	sulphur	
	Caterpillars	***flufenoxuron***	carob fruit bait	Effective control, no environmental emissions
		chlorpyrifos	-	

Table 5.10 Continued

Crop	Pest	Conventional pesticide	Pesticide 2000	Difference in strategy
Cauliflower and broccoli	Aphids	***endosulfan***	***pirimicarb***	Less frequency, reduced environmental emissions
	Caterpillars	***chlorpyrifos***	(***chlorpyrifos***)	Just in seedling trays, reduced emissions
		methomyl	***azadiractin*** + mineral oil	Less toxic to appliers
Tomato	White fly	***methomyl***	***buprofezin***	Less toxic to appliers and for natural predators (1)
		imidacloprid	***cypermethrin***	Reduced environmental emissions
	Aphids	***imidacloprid***	-	Close observation, sufficient control by natural predators
	Caterpillars	***lambda-cyhalothrin***	***azadiractin*** + mineral oil	Less toxic to natural predators (=1), effective for white fly too
		methomyl	***teflubenzuron***	Damage not significant
Onion	Thrips	***isophenphos***	-	
Pepper	Spider mite	***hexythiazox*** + ***dicofol***	sulphur	Less toxic to natural predators and applier, reduced environmental emissions
	Aphids	***pirimicarb*** + ***endosulfan***	-	Effective control by natural predators
Sweet corn	Caterpillars	***lufenuron***	***lambda-cyhalothrin*** + mineral oil	Reduced environmental emissions
		fenitrothion	***bacillus thuringiensis***	
		parathion-methyl	***alfa-cypermethrin***	
		diazinon	-	
Celery	Caterpillars	***methomyl***	***azadiractin*** + mineral oil	Less toxic to appliers and natural predators, reduced environmental emissions
		endosulfan	***cypermethrin*** + mineral oil	

6 Crop protection strategies in Switzerland

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6.1 Introduction

Integrated and organic farms are already well established in Switzerland so the national data for the VEGINECO project could be gathered at commercial pilot farms instead of at experimental farms as in the other countries. Seven integrated and seven organic pilot farms took part in the project.

In Switzerland, vegetable production is carried on small, heterogeneous farms, which often makes it difficult to compare individual farms. Two types of crop rotation are most common: one is based on the susceptibility of plant families to nematodes and soil-born diseases, and lasts three to four years, and the other lasts six to twelve years and includes a high proportion of arable crops. Both types can be found on integrated and organic farms. In order to show the differences and problems in integrated and organic production of field-grown vegetables, three integrated and three organic farms were selected from the 14 pilot farms and combined in pairs. The first pair (CH INT1, CH ORG1) was located in the canton of Zurich, two neighbouring farms that deliver their produce mainly to wholesale distributors (Migros, Coop). The second pair (CH INT2, CH ORG2) was located in the western part of Switzerland and the farms are direct sellers; and the third pair (CH INT3, CH ORG3) was located in the Seeland region, and are farms that deliver to retailers or wholesalers (Annex 1).

The analysis for Switzerland concentrated on the five most important field-grown vegetables in the country: head lettuce, cauliflower, carrots, leek and onions. In the first part of the analysis, the crop protection strategies that are already available are described and evaluated. The second part of the analysis provides an overview of the Swiss results in the VEGINECO research project. In contrast to the other partners, the Swiss research activities were based on the demands of the participating farmers. With many separate experiments on the pilot farms, crop protection strategies were investigated to improve the control of the most important weeds, pests or diseases in lettuce, cauliflower or broccoli, leek, onion and carrot.

Table 6.1a Overview of machinery available for integrated and organic systems in Switzerland

Machine	Type of machine	Width m	Row distance m	Crops
cultivator	-	1.5	-	all crops
reversible plough	-	2-shares	-	crops with long vegetation period
rotary spade machine, spade cultivator	-	1.5	-	all crops
rotary harrow	harrow	3	-	broadcast sown crops
weed harrow, spring weeder	harrow	1.5-6	-	cereals, leek, spinach cabbage
hoe	ridging and inter-row cultivation implement	1.5	0.3-0.75	all row-crops
rotary hoe	ridging and inter-row cultivation implement	1.5	0.3-0.75	leek, carrots, cabbage, crops on ridges
finger weeder	intra- and inter-row cultivation	1.5	0.5	all row crops
inter-row brush	brush	1.5-3	0.25-0.5	all row crops
flamer	open and infrared flamer	1.5-3	-	onions, carrots
mulching sheet laying machine	-	1.5	-	lettuce, fennel, celery
field crop sprayer	broadcast application	3-21	-	all crops
band sprayer	band application	1.5-3	0.3-0.75	row crops
leek/carrot harvester	combine harvesters	1 row	-	leek, carrots, celery

Table 6.1b Overview of available weed control strategies per crop, integrated and organic systems

		Mechanical control						Chemical control			
Crop	System	Row distance (m)	Harrow	Hoe	Brush (instead of hoe)	Flamer	Mulch	Spray application[1]	Herbicide type[2]	Low dose technique	Expected additional manual labour[3]
lettuce	int. + org.	0.5	-	1-2	0-2	-	x	-	-	-	1
cauliflower	int. + org.	0.5	-	2-3	0-2	-	-	-	-	-	1
leek (planted)	int.	0.3-0.5	-	2-3	0-2	-	-	FF	post	x	2
leek (planted)	org.	0.3-0.5	1-2	2-3	0-2	-	-	-	-	-	3
onion (sown)	int.	0.25-0.5	-	2-3	0-2	-	-	FF	pre/post	x	3-4
onion (sown)	org.	0.25-0.5	1	3-5	0-2	1	-	-	-	-	5
carrot	int.	0.3-0.5	-	2-3	0-2	-	-	FF	post	x	3
carrot	org.	0.3-0.5	-	2-5	0-2	1	-	-	-	-	6

1. FF = full field
2. pre = pre-emergent, post = post-emergent
3. additional manual labour needed: 1 = < 20 hours ha^{-1}, 2 = 20-40, 3 = 40-60, 4 = 60-80, 5 = 200-300, 6 = 300-500

6.2 Weed control strategies

The main goal in weed control is to minimise the input of herbicides and their impact on the environment in integrated production. This was accomplished by using post-emergent herbicides or the introduction of machinery for band application. In organic farming, herbicides are not allowed, and reduction of manual labour input is important. In both farming systems, the goal is to optimise mechanical weed control and the use of mulching material.
In the following section, standard weed control strategies for lettuce, cauliflower, leek, onion and carrot in integrated and organic farms are summarised (see also Tables 6.1a and 6.1b).

Lettuce
In the lettuce crop, weeds could not be tolerated in the first half of its growing cycle. Therefore, the threshold period lasts 2-4 weeks after planting (Müller -Schärer and Baumann, 1993). The use of mulching materials, e.g. plastic films or paper controlled weeds effectively. Without mulching, two or three treatments with a hoe or brush were necessary. Slight ridging in the crop rows was possible to prevent weeds. In general, mechanical weed control was effective for the lettuce crop. In integrated farming, the pre-emergent herbicide ***propyzamide*** is registered, but not recommended.

Cauliflower
Cauliflower is a very competitive crop and develops quickly. The threshold period lasts five to seven weeks. Two or three treatments with a weed harrow, a hoe, a rotary hoe or a finger weeder were effective. The first treatment was needed as soon as the crop was well rooted and this was in an early stage of weed development. In the late cropping period, ridging of the crop was used to control weeds in the rows. In general, no herbicides were used in integrated farming. If chemical control was still necessary, ***propachlor***, ***pendimethalin***, ***metazachlor***, ***napropamide***, ***chlorthal-dimethyl*** and various graminicides were applied. Cabbage herbicides provided a limited efficacy and the most important weeds were *Brassicaceae*.

Leek
In planted leek, weeds could not be tolerated in the first 10 weeks of the cropping period. As soon as plants were well rooted, use of a harrow was possible. In the later stages, two to three treatments with a hoe or a rotary hoe including ridging were performed. In addition, split application and low dosage systems of the herbicides ***ioxynil***, ***methazol***, ***linuron***, ***monolinuron***, ***pendimethalin***, ***propachlor*** and various graminicides were used in integrated production.

Onion
Onion develops slowly and is high sensitively to competition from weeds. The threshold period lasts 13 to 16

weeks. In integrated farming, split application and low dosage systems of the herbicides ***ioxynil***, ***oxyfluorfen***, ***propachlor***, ***pendimethalin***, ***chlorthal-dimethyl*** and various graminicides were used. In organic farming, the false seedbed technique was indispensable for seedbed preparation. Flaming was possible until the seed leaf stage of the crop began. From the one-leaf stage onwards, a harrow can be utilised. In later crop stages, a hoe must be used several times and manual labour was necessary.

Carrot

Carrot is a strong competitor after relatively slow development as seedlings. This crop takes two to four weeks to emerge. After the two-leaf stage, weeds cannot be tolerated for six weeks. Low dosages of ***linuron***, ***chlorbromuron***, ***metoxuron***, ***monolinuron***, ***pendimethalin*** and various graminicides were applied at the integrated farms. Pre-emergent treatments were used only if weed pressure was high. For organic farms, false seedbed preparation was very important. If there the weed pressure was high, then flaming was recommended just before crop's emergence. After its establishment, two to five treatments

Table 6.2 Overview of tested weed control strategies at Swiss pilot farms

Crop	Strategy	Results	Managed by	Remarks
lettuce	larger distance between plants (Kesper et al., 2000b)	- larger distance between plants had no impact on the number of weeds per unit	farmers	- part of an interdisciplinary trial: larger distance between plants and/or cover soil with black mulch layer and/or cropping on ridges, see also pest and disease control
cauliflower	weed control by ridging with a harrow or ridging implements or rolling cultivator in spring (Imhof and Baumann, 1999)	if a harrow was used in spring, the ridging impact depended on the speed - the ridging implements had -the best ridging and weed control effect - the effect of the rolling cultivator depended on the driving speed and on the adjustment of the star implements - the use of ridging implements or an accurate adjusted rolling cultivator allowed an effective mechanical weed control	farmers	- ridging tools are recommended for small farms with many small crops because they are inexpensive and easy to adjust - the rolling cultivator is useful for farms with large fields and crops, which allow the machine to be used at high speeds, how ever, this machine is unsuitable for stony soils
carrot	false seedbed technique	- three treatments with the harrow: 4 weeks, 3 weeks and 1/2 week before sowing of carrots resulted in the best mechanical weed control - the false seedbed technique reduced the manual labour input in carrot crops	farmers	- the false seedbed technique shouldbe combined with flaming one week after sowing just before emergence of the carrots to achieve an optimal weed control
	crops on ridges or intercropping with subterranean clover	- weed control was no problem due to the low weed pressure in the field	- ridging was carried out by farmers with adequate machinery - limited inter-cropping was carried out by farmers	- part of an interdisciplinary trial, see also pest and disease contro - in general, weed control on ridges requires adequate and precisely adjusted machinery - a hoe or ridges can cause green heads on carrots

were usually carried out with a hoe or a brush, later on with a rotary hoe or a ridging hoe. Usually a manual hoe was necessary for weeds up to 500 hours ha^{-1}.

Weed control strategies tested in field experiments at pilot farms

The experiments at the pilot farms focused on the impact of larger distance between plants on weed density in lettuce, suitability of different machines for weed control in cauliflower, false seedbed technique, and the impact of ridging and intercropping on the weed density in carrots (Table 6.2). Weed control strategies in lettuce and carrot are part of complex crop protection strategies (interdisciplinary trials).

6.3 Disease and pest control strategies

For disease and pest control, reducing the input of fungicides and insecticides is a priority for integrated and organic farms. From the time that wholesale distributors started to sell organic food, the quality requirements and the crop protection strategies for organic vegetables have gradually been adjusted to integrated standards. In lettuce, for example, up to four treatments to eliminate leaf aphids are applied in both types of farming systems to achieve the desired quality (Kesper and Imhof, 1998a).

The studies focused on the main diseases and pests in lettuce, cauliflower and broccoli, leek, onion and carrot (Table 6.3). They caused significant losses in yield at one third of the integrated pilot farms and at half of the organic pilot farms (Kesper et al., 2001). The crops were inspected regularly at the critical points during the season when the most problematical diseases and pests usually occur. Recommendations for treatments were based on trapping methods and threshold concepts, which led to a reduction of pesticide inputs, especially at sites with a low pest pressure. Tables 6.4 and 6.5 and the following sections present the monitoring methods that are already available and cropping strategies that are well known in Switzerland. In another section, an overview is presented on the Swiss research activities and their results that focus on new trapping methods, threshold concepts and cropping strategies.

6.3.1 Disease control strategies per crop

Lettuce

The main problems in lettuce production are the fungi of the bottom rot complex (*Botrytis*, *Sclerotinia*, *Rhizoctonia*) and downy mildew (*Bremia lactucae*). Plant material, which is infested with bottom rot, should be taken out of the field, but this does not seem to be manageable. The farmers plough it in. ***Iprodione*** is the preventive fungicide most often chosen for *Botrytis* and *Sclerotinia* with additional effects on *Rhizoctonia*. ***Cyprodinil*** and ***fludioxonil*** are registered. The time for application is limited to 14 days after planting because the bottom sides of the leaves and the stem are splashed. After the sixteen fold to twenty-two fold resistance to *Bremia* in *Lactuca spp*. broke down during the past few years, curative treatments became necessary again with ***mancozeb/metalaxyl***, ***mancozeb/cymoxanil/ oxadixyl***, ***fosethyl-aluminium*** and ***propamocarb***.

Cauliflower and broccoli

Alternaria brassicae is one of the most important diseases in cauliflower and broccoli. Especially, crops in the autumn were infested. They were treated when the first spots appeared. ***Iprodione*** and ***difenoconazole*** had the greatest impact. Removing infested single plants was necessary to reduce the pressure from *Plasmodiophora brassicae*. The use of the disinfecting calcium cyanamide was practised even when this opposed the targets for nitrogen input. Curative copper applications controlled *Xanthomonas campestris* however the effectiveness was limited.

Table 6.3 Maximum yield losses caused by most important pests and diseases at seven integrated and seven organic Swiss pilot farms in the years 1998-2000

Crop	diseases and pests	maximum yield loss per crop: integrated pilot farms	organic pilot farms
Lettuce	downy mildew	50%	100%
	bottom rot	85%	80%
	leaf aphids	70%	0%
Cauliflower/broccoli	gall midge	100%	80%
	caterpillars	50%	80%
Leek	thrips	15%	100%
	leek moth	45%	55%
Onion	downy mildew	100%	100%
Carrot	carrot fly	5%	10%

Table 6.4 Overview of available disease control strategies per crop in integrated and organic farming

		Prevention						Need for control		Control	
Crop	Disease	MCR	Nitrogen	Seeds plants	Variety	Plant distance	Incorporation/removing crop residue	Signal	Damage threshold	Physical	Chemical
lettuce	*Sclerotinia* *Rhizoctonia*	X	X	X	X	X	(X/remove)	-	-	X	X
	Botrytis c. *Bremia*	X	X	X	X	X	X/plough in	X	-	?	X/XX
cauliflower/ broccoli	*Alternar. b.*	X	X	X	-	X	X/plough in	X	-	-	X/XX
	Plasmodio.	X	CaCN2	-	X	-	X/remove	-	-	-	-
	Xanthomo.	X	X	X	X	X	X/plough in	X	-	-	(X)
leek	*Alternar. p.*	X	X	-	-	X	X/plough in	X	clear visible	-	XX
onion	*Botrytis a.*	X	XX	X	X	X	X/plough in	-	-	-	X/XX
	Botrytis s.	X	XX	-	-	-	X/plough in	X	-	-	X/XX
	Peronospo.	X	X	-	-	XX	X/plough in	X	-	-	X/XX
carrot	*Alternar. d.*	X	X	X	XX	X	X/plough in	X	-	-	X/XX
	Alternar. r.	X	-	X	XX	-	-	-	-	-	-

xx = very effective and manageable
x = limited effectiveness and/or manageable
- = not relevant or possible

Leek
The main disease of leek is *Alternaria porri*. This is the only disease for which there is a damage threshold: Farmers wait to apply ***difenoconazole*** until the plants show clear purple spots. One or two preventive treatments for *Botrytis* neck rot of onions were carried out with ***iprodione***. This is also effective against *Botrytis* leaf spots. ***Mancozeb/metalaxyl***, ***mancozeb/cymoxanil/oxadixyl*** or ***chlorothalonil*** were applied when the first symptoms of *Peronospora destructor* appeared. Serious infestations need to be controlled weekly.

Carrot
Alternaria radicina is found in the seedling stage of carrot and could be eliminated with seed dressing of iprodione. For *Alternaria dauci* on the carrot leaves, ***iprodione***, ***difenoconazole***, ***chlorothalonil*** and several dithiocarbamates were applied when the first spots appeared. At very humid sites, preventive treatments were necessary.

6.3.2 Pest control strategies per crop

Lettuce
In Switzerland, it is hardly possible to grow lettuce that is free of leaf aphids. The success of a crop cover (cotton net) mainly depends on the infestation of the young plants, which should be clean. Applications of soaps, pyrethroids plus ***piperonil butoxide***, ***rotenone*** and Quassia extracts are allowed in organic farming. ***Diafenthiuron***, ***pymetrozine***, several organophosphates, pyrethroids and carbamates could be used in integrated systems.

Cauliflower and broccoli
In Cauliflower and broccoli, caterpillars (*Mamestra brassicae, Pieris rapae*, *Plutella xylostella*) and gall midges (*Contarinia nasturtii*) were the greatest problems in both farming systems. Early warning systems use light traps or yellow water traps catch individuals and damage thresholds exist for nearly all of the important pests.

Table 6.5 Overview of available pest control strategies per crop in integrated and organic farming

		Prevention				Need for control		Control		
Crop	Pest	MCR	Nitrogen	Seeds and plants	Variety	Signal	Damage threshold	"Physical"	Chemical organic	Chemical integrated
lettuce	aphids	-	x	(x)/net	x	x	-	(x)/net	x	x
	root aphid	-	(x)	(x)/net	(xx)	x	(x)	(x)/net	-	x
	cutworms	-	(x)	-		x	(x)	-	-	xx
	slugs	?	(x)	-		x	-	-	x	xx
cauliflower and broccoli	caterpillars	-	(x)	(x)/net		x	x	(x)/net	x/B.t.	x
	cabbage fly	-	(x)	x/net	(x)	x	x	xx/net	-	x
	gall midge	-	(x)	(x)/net		(x)	in development	x/net	-	x
	aphids	-	x	(x)/net		x	x	(x)/net	x	x
	slugs	?	(x)	-		x	-	-	x[1]	xx
	flea beetles	-	(x)	(x)/net		x	(x)	x/net	-	x
leek	thrips	-	(x)	(x)/net	x	x	-	xx/net/ryegrass	x	x
	leek moth	-	(x)	(x)/net		x	(x)	x/net	x/B.t.	xx
onion	thrips	-	(x)	(x)/net		x	-	(xx)/net	x	x
carrot	carrot fly	-	(x)	seeding time	(x)	x	x	xx/net	-	x

xx = very effective and manageable
x = limited effectiveness and/or manageable
- = not relevant or possible

1. Phasma Rhabditis

Therefore, preventive applications are usually not necessary. The use of cabbage fly nets as crop cover was only done in organic farming. ***Bacillus thuringiensis*** varieties kurstaki and aizawai are applied in both systems to control caterpillars. However, they are effective only against the first two larvae stages. Furthermore, several carbamates, organophosphates and pyrethroids were used in integrated systems. There were no acceptable products for gall midge control in organic farming. ***Diazinon*** or pyrethroids should be applied twice in the integrated production at sites of possible infestation during the main Contarinia flight.

Leek and onion

Controlling thrips (*Thrips tabaci*) in leek and onion presented one of the main problems in both farming systems. The leek variety 'Bulgina' had the best tolerance in the fields. If the use of a net is possible, this could be more effective than undersowing with Lolium perenne or Trifolium subterraneum. Both "physical" control methods could achieve a better rate of success than chemical control. Damage thresholds cannot be defined yet as long as the requirements for quality do not allow any spots on leek. Weekly applications of pyrethroids plus piperonil butoxide or rotenone were possible in organic systems. Chemical control was also a great problem for integrated farmers because the insecticides now available seem to be less effective. Therefore, it was necessary to change between organophosphates or carbamates and pyrethroids, which also controls leek moths.

Carrot

Psila rosae caused the greatest damage in carrot crops. Yellow sticky traps monitor the flight of the carrot fly. If the damage threshold, based on the number of flies caught, was exceeded, soil treatments were carried out

Table 6.6 Use of preventive strategies and threshold methods at seven integrated and seven organic pilot farms

Strategies	Number of integrated farms	Number of organic farms	Percentage of all 14 farms	Comments
resistant varieties	6	6	about 86%	-
crop cover/nets	5	5	about 72%	mainly in small radish and radish, cauliflower and broccoli
damage thresholds	2	1	about 21%	72% of all farms would use thresholds if they were more simple
sticky traps	1	2	about 21%	mainly carrot fly traps
crop undersowing	0	0	0	about 36% of all farms had poor experiences with crop undersowing

with ***chlorfenvinphos*** or ***furathiocarb*** at integrated farms. To limit degradation due to micro-organisms, the soil insecticides should be applied only once in two years on the same plot. Crop covers mainly were used in organic systems.

6.3.3 Evaluation of available strategies for crop protection from the perspective of the Swiss farmers

Few of the available preventive strategies and threshold concepts are actually put into practice in contrast to chemical controls as the results of a survey of Swiss farmers participating in the pilot project show (Table 6.6). The most popular strategy is the choice of resistant varieties. Many pilot farms use crop covers to prevent pest infestations, however, managing nets effectively was still a big problem. The use of damage thresholds and sticky traps for monitoring was limited. The majority of the farmers found these methods still too complicated and too time-consuming. In practice, inspecting fields for the presence or absence of pests or diseases is the most common threshold method. Crop undersowing is a modern cropping system not yet available for practical use. The farmers' poor experiences indicate that changes in cropping systems have to be tested and developed in practice to obtain manageable results. Farmers cannot accept too many risks and cannot spend too much time on extra tasks for organic farming if they want to stay in business. Therefore, the research program focused on simplifying available monitoring methods and on testing alternatives. Furthermore, the efficacy of new cropping strategies was investigated in field experiments on the pilot farms. The results are presented in the next section.

6.3.4 Overview of Swiss research results in disease and pest control

The results of regular crop inspection and field experiments have been subdivided into three different tables containing trapping methods, threshold concepts and cropping strategies. Methods used to control diseases or pests are presented in Tables 6.7 to 6.9. The results are listed for each crop. In addition to the results, comments are included concerning management practices, the effects from the pesticide input and general remarks. The most important results are summarised in the following sections.

Lettuce

The rapid growth of lettuce could compensate for losses caused by downy mildew and could lead to higher yield of marketable heads. Therefore, all cropping strategies should be used that support rapid growth of the crop such as a larger distance between plants, cropping on layers of mulch and cropping on ridges. In addition, crops of mixed varieties with different resistance to downy mildew can reduce the risk of infestation and can slow down the selection of new downy mildew strains. Growing Nasonovia resistant varieties can reduce the need for insecticide input in lettuce. However, some insecticide treatments are still indispensable, especially at sites with high pressure from the potato aphid, *Macrosiphum euphorbiae*.

Cauliflower and broccoli

In cauliflower and broccoli crops, the cabbage gall midge *Contarinia nasturtii* can be monitored using transplanted broccoli trap plants. However, this method is very time consuming and requires adequately trained personnel. Yellow water traps did not show the course of the flight, although the beginning of the flight was registered.

Table 6.7 Overview of trapping methods for each crop tested at Swiss pilot farms and their impact

Trapping method	Monitored pest or disease	Relation to crop inspection data	Manageable (by)	Impact	Comments
Lettuce					
yellow water trap	leaf aphids *(Nasonovia ribisnigri, Macrosiphum euphorbiae, Aulacorthum solani, Myzus persicae, Uroleucon sonchi)*	not tested	mot manageable	the impact of pesticide use was not tested	too time-consuming
spore trap (Siegfried et al., 1996)	downy mildew (*Bremia lactucae*)	captures were not representative not tested	not manageable	the impact on the pesticide use was	• only air-born conidia could be caught with the spore trap • primary infection units like oospores or mycelia could not be detected • determining conidia by shape, colour and size was not sufficient, a specific identification method would be necessary
Cauliflower/broccoli					
yellow water trap with bait (Finch and Skinner, 1982)	cabbage fly (*Delia radicum)*	not tested	manageable by experts only	timing of pesticide treatments was improved	traps could be replaced by inspection of oviposition in the field
yellow water trap with bait (Finch and Skinner, 1982)	gall midge *(Contarinia nasturtii)*	prediction of infestation was not possible because the course of could not be monitored the flight	manageable by experts only	regular chemical control could not be avoided in regions with a high gall midge pressure since the risk of infestation of a certain crop could not be predicted	additional investigations are necessary to improve the water trap method or to develop a reliable pheromone trapping system
pheromone water trap (Freuler et al., 1991)	cabbage moth Mamestra brassicae	• captures depended on the farm site and the trap site • captures of the first generation were very small and correlated poorly to the infestation of the crop • captures of the second generation increased parallel to the percentage of infested plants	manageable by experts only	• the impact on the pesticide use was not tested • predicting infestation was not possible	• traps installed at end of April or mid-May, first captures in traps at end of May • first observation of egg batches or young Mamestra caterpillars on the crop in mid-May, when crop inspection started • crop inspection seemed to be more effective and supplied more reliable data

Additional studies are necessary to improve monitoring and prediction methods. Otherwise, it will be difficult to avoid the use of regular chemical control in practice.

Leek

A test of the potential resistance of onion thrips to pesticides had similar results at two sites with different leek growing intensities: among the tested registered insecticides, the carbamate ***carbosulfan*** was the most effective one. The synthetic pyrethroid ***lambda-cyhalothrin*** was not as effective.

Leek plants in monocrops or mixed crops with celeriac had a similar amount of infested plants in the growth period and a similar amount of thrips on the plants at harvest time. The damage caused by thrips resulted in non-marketable leeks in both treatments.

Onions

The use of planted onions instead of sown onions reduces the loss of yield caused by downy mildew even in a short summer crop.

Carrots

The success of cropping systems with intercrops, for

Table 6.7 Continued

Trapping method	Monitored pest or disease	Relation to crop inspection data	Manageable (by)	Impact	Comments
broccoli trap plants (Theunissen et al., 1997)	gall midge *(Contarinia nasturtii)*	• larvae of the gall midge could be observed in the hearts of the broccoli trap plants whereas in the respective crops only gall midge damage was observed • 4-48% of infested trap plants resulted in 10-20% infested broccoli crop plants • 68-100% of infested trap plants resulted in zero or an approximately low number of infested cauliflower crop plants	manageable by experts only	• impact of the pesticide use was not tested • up until now, trap plant or crop inspection was the only method to monitor the cabbage gall midge and to indicate the risk of infestation	• very labour intensive • in the cauliflower crop, it was more difficult to inspect the heart of the young plant than in broccoli • according to the farmers' observations, cauliflower seemed to be attacked less by gall midges than broccoli • for a reliable correlation of infested trap plants to infested crop plants, additional studies are necessary
Leek					
blue sticky trap (Kesper et al., 2000a)	thrips *(Thrips tabaci)*	• numbers of adults thrips caught correlated better with the number of adults per plant than with the number of thrips larvae per plant • the larvae caused more damage than the adults • sticky blue traps indicated the point of time of the thrips mass invasion into the leek crop	manageable by trained farmers and extension service	• even low thrips density has to be controlled in both, nursery and field • leek seedlings should be treated if 10 thrips per trap and week are caught • in the field the use of a critical number of thrips caught was useless during the summer period because the thrips pressure was too high	in the most critical period from July until September onion, head cabbage, fennel and lettuce should be inspected also, thrips infestation caused severe damage or total yield loss
pheromone trap (Freuler et al., 1991)	leek moth *(Acrolepiopsis assectella)*	• captures depended on the farm site and the trap site • one or two weeks after the main flight of the second generation, the first damage was observed on summer leek plants at the beginning or middle of July • the main flight of the second generation was indicated by captures of up to 40 or 50 leek moths per trap and week	manageable by trained farmers and extension service	• allowed adequate timing of control measures on organic farms • on integrated farms, treatments for thrips was control leek moth, therefore, this pest was less important	captures indicated the flights of three generations: first generation with main flight in March/April, second in June/July, third in August
Carrot					
orange sticky trap (Freuler et al., 1991)	carrot fly *(Psila rosae)*	treatments according to the threshold of carrot flies caught limited the loss of yield to 5% on an integrated farm	manageable by trained farmers and extension service	the number of treatments that were reduced depended on the carrot fly population at the site and its flight course in the particular year	• first captures end of April • traps caught the flights of two (sometimes three) generations: first generation with main flight in May, second in September/October, an additional main flight could be observed in July/August depending on site and year

example, in carrots depends on the weather conditions at the site, its soil and the sowing dates of the crop and the intercrop. These systems are too time-consuming, too complicated and not reliable enough.

Table 6.8 Overview of threshold concepts for each crop tested at Swiss pilot farms and their impact

Threshold method	Monitored pest or disease	Implementation	Manageable (by)	Impact	Comments
Lettuce					
period threshold -critical percentage of infested plants- (Fischer and Terrettaz, 1999)	leaf aphids *(Nasonovia ribisnigri, Macrosiphum euphorbiae, Aula-corthum solani, Myzus persicae, Uroleucon sonchi)*	• 20 lettuce plants per field were inspected regularly until 10 to 14 days before harvest • from mid-May to beginning of July (and from September to beginning of October) the threshold level was 10% of plants occupied with wingless aphids • in the remaining months, a threshold level of 40% infested plants was used • heads with zero to five wingless aphids maximum are defined as marketable heads	manageable by trained farmers and extension service	• even with accurate application of the threshold values, the farmer could harvest non-marketable heads in late spring, summer and autumn • ate spring time with the highest aphid pressure was the most problematic crop period	the threshold values should be tested again in randomised field trials number of aphids could be tolerated, for example, ten aphids per head, because it was very difficult to reach the target by applying one or two treatments not only in late spring time
Cauliflower/broccoli					
critical number of eggs per plant -German threshold- (Albert et al., 1997)	cabbage fly *(Delia radicum)*	• weekly inspection of 5 groups of 5 plants each at the border of the field during the first two weeks after planting • 10 eggs per plant in maximum were tolerated	manageable by trained farmers and extension service	timing of pesticide treatments was improved	• traps could be replaced by inspection of oviposition in the field • inspection of 10 plants per field to save time
first event method (Freuler et al., 1991)	caterpillars *(Mamestra brassicae, Pieris rapae, Plutella xylostella)* and cabbage aphid *(Brevicoryne brassicae)*	• weekly inspection of 5 groups with 10 plants each per field after planting till harvest, the groups were chosen at random • the visual assessment stopped as soon as first caterpillars or aphids were found ('first event') • graphic analysis of the sampling data	manageable by experts or extension service	• the application of the threshold method led to yield loss caused by caterpillars about 10% • regular chemical control could not be avoided in regions with a high gall midge pressure because the risk of infestation of a certain crop could not be predicted	very time-consuming, especially at sites with a low pest pressure

Table 6.8 Continued

Threshold method	Monitored pest or disease	Implementation	Manageable (by)	Impact	Comments
critical number of cabbage pests on 10 plants (VSGP, 2000 and Theunissen and den Ouden, 1987)	caterpillars *(Mamestra brassicae, Pieris rapae, Plutella xylostella)* and cabbage aphid *(Brevicoryne brassicae)*	• weekly inspection of 2 groups with 5 plants each per field after planting until harvest, one group was chosen at the border of the crop, the other in the middle of the field caterpillars: • the number of young and older caterpillars on the ten inspected plants was counted • the threshold was defined as 10-30 young caterpillars or 1-4 older and bigger caterpillars on 10 plants cabbage aphid: • the number of plants infested with cabbage aphids was recorded • the threshold was defined as 4 plants infested with cabbage aphid within a minimum of 10 plants	manageable by trained farmers or extension service	• how many treatments could have been reduced depended on the cabbage pest pressure of the particular site • regular chemical control could not be avoided in regions with a high gall midge pressure since the risk of infestation of a certain crop could not be predicted	• the first event method can be replaced by the critical number of caterpillars on 10 plants because it is less time-consuming • 10 plants is considered to be the minimum sample size to avoid gross sampling errors • 20-25 plants per crop should be inspected to assess the risk of infestation with the gall midge
Leek					
critical number of plants infested by thrips -German threshold- (Albert et al., 2001)	thrips *(Thrips tabaci)*	• 20 plants per leek crop were inspected after planting until harvest • the number of plants infested with thrips were recorded • the German threshold was defined as 25-50% of leek plants infested with thrips	manageable by trained farmers and extension service	• the German threshold for thrips in leek could be used only on sites with a small thrips population • its use was useless on the majority of the Swiss pilot farms	• even low thrips density has to be controlled to avoid a mass infestation in the summer period • in the most critical period from July until September onion, head cabbage, fennel and lettuce should be inspected too, thrips infestation could cause in those crops severe damage or total yield loss

Table 6.9 Overview of cropping strategies for crop protection tested at Swiss pilot farms and their impact

Cropping strategies	Controlled weed, pest or disease	Results	Manageable (by)	Impact	Comments
Lettuce					
crops of red coloured varieties, varieties resistant to lettuce aphid (Nasonovia ribisnigri) or to downy mildew (Bremia lactucae) (Kesper et al., 1998b and Kesper et al., 2000b)	leaf aphids *(Nasonovia ribisnigri) or downy mildew (Bremia lactucae)*	• red lettuce varieties were attacked less by the lettuce aphid (Nasonovia ribisnigri) • varieties resistant to the lettuce aphid proved to be worthwhile • varieties resistant to some new strains of downy mildew (BL 17-22) were, nevertheless, infested at certain sites	manageable by farmers	• the pesticide treatments that were reduced by using red coloured or resistant lettuce varieties depending on the aphid species composition or downy mildew strain composition at the site • the pesticide input depended on the aphid pressure and on the climatic conditions of the particular year	• for downy mildew, it is no longer possible to recommend a single variety for specific regions, because all available varieties could be infested by downy mildew strains • crops with a variety mixtures and different resistance to downy mildew reduces the risk of infestation and the selection for new downy mildew strains is lower
polyethylene net as crop cover	leaf aphids *(Nasonovia ribisnigri, Macrosiphum euphorbiae, Aula-corthum solani, Myzus persicae, Uroleucon sonchi)*	• the lettuce heads were infested with aphids before they were covered with the net, therefore, covered and non-covered heads were not marketable at harvest • heads badly damaged and weed grew faster under the net	limited manageable by farmers	the number of treatments that can be reduced by the use of a net depends on the timing of covering the crop	if the control of aphids fails, the negative impact on crop cover is dominant in lettuce
silver mulch layer (Kesper et al., 1998b)	leaf aphids *(Nasonovia ribisnigri, Macrosiphum euphorbiae, Aula-corthum solani, Myzus persicae, Uroleucon sonchi)*	• cropping on silver mulch layer had only a repellent effect on aphid colonisation in the first week after planting • afterwards this effect disappeared which might have been due to an Increasing covering of the film by the growing lettuce	limited manageable by farmers	insecticide treatments could not be replaced by the use of silver mulch layer because aphid colonisation before hearting of the crop could not be prevented	• silver mulch layer could not be recommended to control aphids in lettuce • additional problems were its low strength and its poor degradation in the soil
larger distances between plants and/or covering soil with black mulch layer and/ or cropping on ridges (Kesper et al., 2000b)	*downy mildew (Bremia lactucae)* and bottom rot *(Rhizoctonia solani)*	• lettuce grown with larger distances between plants and on flat or on ridged soil covered by black mulch layer resulted in higher numbers of marketable heads, because losses caused by downy mildew were reduced • different treatments showed no impact on the infestation by *Rhizoctonia*	limited manageable by farmers	• neither downy mildew nor Rhizoctonia solani were controlled, however, the cropping strategies supported a rapid growth of the crop • the rapid growth of the lettuce crop compensated losses caused by downy mildew and led to a higher yield of marketable heads	• interdisciplinary trial, see also weed control • the use of these cropping strategies is limited by the availability of inexpensive ridging machinery and of degradable mulch layers • the effect of these cropping strategies on the crop depends on the climatic conditions at a site, the pH of the soil, the inclination of the cropping area and probably, the availability of nitrogen, as some farmers observed • an increase in rotting, for example, caused by the use of black mulch layers
mulching material consisting of wooden fibres, mulching t compos or metal fence for slug control	slugs *(Deroceras reticulatum, Arion lusitanicus)*	due to unfavourable conditions for slugs during the trial and the small population of *Arion lusitanicus* at the chosen site, it was not possible to judge the impact of the tested slug control strategies	limited manageable by farmers	the effectiveness of a fence for slug control depended on prevention of overgrowth by grass or little bushes at another site	fences for slug control were very expensive and not very popular on organic farms

Table 6.9 Continued

Cropping strategies	Controlled weed, pest or disease	Results	Manageable (by)	Impact	Comments
Leek					
'carrot fly net' as crop cover	leek moth *(Acrolepiopsis assectella)*and purple blotch *(Alternaria porri)*	the infestation with leek moth and Alternaria was similar in covered and non-covered plots	limited manageable by farmers	the effectiveness of a crop cover in taller crops such as leek was limited because it was not practical and very time-consuming to close all holes in the	net one of the pilot farms used the net in leek as protection against frost
choice of pesticides to avoid insecticide resistance (Kesper et al., 2000a)	thrips *(Thrips tabaci)*	the synthetic pyrethroid **lambda-cyhalothrin** did not have equal effectiveness against thrips in insecticide tests at different sites	manageable by farmers	to avoid developing resistance, it is recommended to choose insecticides with different modes of action for pest control in a crop	• the hypothesis for resistance of Thrips tabaci to **lambda-cyhalo-thrin** or other synthetic pyrethroids was supported by additional insecticide trials done by Swiss companies • this is of relevance to thrips control on organic farms because some registered products contain also pyrethroids • it is also important to note that **lambda-cyhalothrin** is also intensively used at certain sites to control the gall midge in cauliflower and broccoli
mixed cropping of celeriac and leek (Kesper et al., 2000a)	thrips *(Thrips tabaci)* and leek moth *(Acrolepiopsis assectella)*	• leek monocrops and mixed crops with celeriac showed a similar amount of infested plants in the cropping period and a similarly high amount of thrips on the plants at harvest • the thrips damage resulted in non-marketable leeks in both plots • leek moth damaged mixed crops of leek twice as much as monocrops of leeks	limited manageable by farmers	• the number of treatments for thrips in summer leek can be reduced by a mixed crop of leek and celeriac, depending on the thrips pressure at the site • leek moth damage could increase in a mixture of these crops, which might have to be controlled	mixed crops of leek and celeriac can not be recommended to control Thrips tabaci in leeks at sites with a high thrips population in the summer
Onion					
preconditioning for earlier development (Kesper et al., 2001)	downy mildew *(Peronospora destructor)*	the use of planted onions instead of sown onions reduced the yield loss caused by downy mildew in a short summer crop	manageable by farmers	the number of treatments that can be reduced by the use of planted onions instead of sown onions depends on the first occurrence of the disease in a region in the particular year	due to the warm and humid climatic conditions in the last spring, downy mildew infested summer onions in May
Carrot					
cropping on ridges or intercropping with subterranean clover Kesper et al., 2001)	carrot fly *(Psila rosae)* and black root rot *(Chalaropsis thielavioides)*	carrot fly and black root rot were not sufficiently present so it was not possible to assess the impact of intercropping and ridging on their infestation	very limited manageable by farmers	impact of pesticide use could not be assessed	• interdisciplinary trial, see also weed control • the success of cropping systems with intercrops depends on the weather conditions of a site, its soil, the sowing dates of crop and intercrop and the farmer needs a lot of experience • these cropping systems are not reliable, too complicated and too time-consuming

6.4 Testing and improving

Control strategies, quality production and manual weeding

Figures 6.1 and 6.2 present the results for quality of production of five selected crops at the pilot farms for pair 2 (CH INT2, CH ORG2). In 2000, yield and quality of the crops reached or exceeded even the good agricultural practice level (GAP) at both farms, except the head lettuce crop at the integrated farm and the onion crop at the organic farm. The integrated farm attained 91.5% of the GAP and the organic farm 87.2% on average for the five crops. However, the dramatic variation in yield over the years at the organic and at the integrated farms was caused by the interaction of pests, diseases and extreme weather conditions. The results for quality are more difficult to interpret.

Bottom rot in head lettuce and hail caused a reduction in quantity at the integrated farm CH INT 2. Caterpillars, cabbage aphid and cabbage fly reduced yield in cauliflower. Muddy soil and a hailstorm led to poor germination and a great variation in yield for carrots. In addition, onion showed a lower yield after a hailstorm.

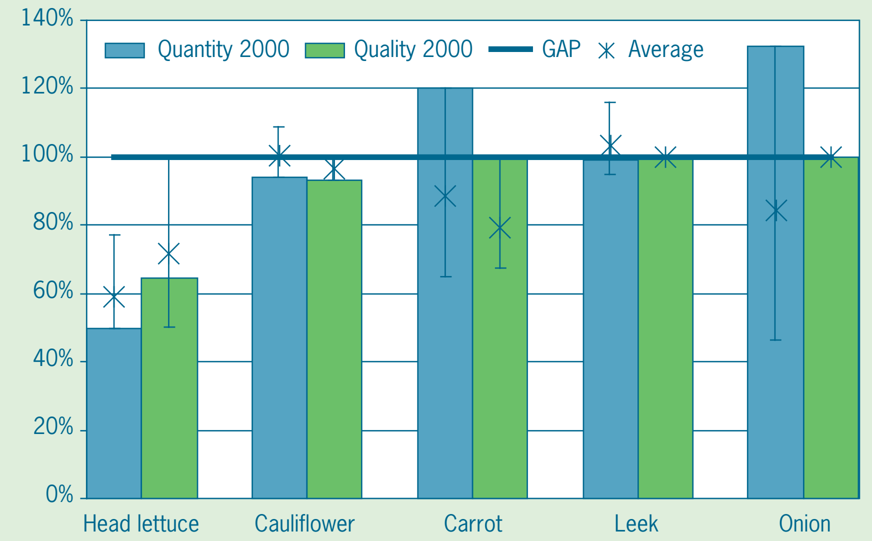

Figure 6.1 Comparison of good agricultural practice (GAP) and quality production of integrated farm CH INT2 2000 (variation 1998-2000)

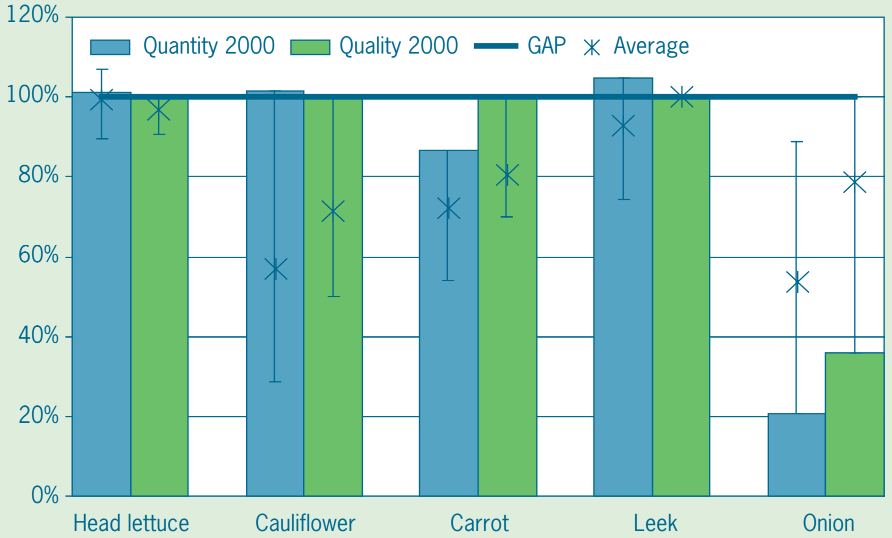

Figure 6.2 Comparison of good agricultural practice (GAP) and quality production of organic farm CH ORG2 2000 (variation 1998-2000)

At the organic farm, CH ORG2, downy mildew and a hailstorm caused damage to onion. Caterpillars, cabbage aphid, slugs and gall midge led to yield loss in cauliflower. In carrot, quantity was reduced by poor germination. However, the analysis of the reductions for each farm is very site-specific due to pest and disease pressures and their occurrence with extreme weather conditions. Therefore, general crop protection strategies have to be improved and adapted to the specific conditions at a site. However, yield is a result of many interacting factors. An optimal farm specific cropping strategy has a limited impact.

In contrast to pests and diseases, there was no negative impact of weeds on quality production identified. A comparison with the other countries of the hours of manual weeding per crop is presented in Figure 6.3, derived from the farmers' assessment in 1997. Using this parameter, the success of the weed control strategy was quantified. Weed control in lettuce, cauliflower and partially in leek was done mechanically in both farming systems. Therefore, the manual labour input was comparable in these crops. However, in sown crops, carrot and onion, the hours of manual weeding were up to ten times higher at the organic farms than at the integrated farms that use herbicides.

In general, weed pressure was higher in crops grown on organic soils and need more manual labour input than on mineral soils in both farming systems.

Pesticide use and emission

In contrast to the other partners, the Swiss results for pesticide use and emissions are quantified as the number of pesticide treatments. They replace the parameters Pesticide Active Ingredient Input (PESTAS) and Environment Exposure to Pesticides (EEP). From the Swiss perspective, active ingredients alone are of very limited use. Very active compounds such as synthetic pyrethroids are used in very small amounts of active ingredients per ha, but can have very serious side effects. The Swiss farms determine the pesticide input and the pesticide emissions based on the number of treatments because every treatment has known or unknown negative side effects. In addition, the input of active ingredients is compared with the other countries.

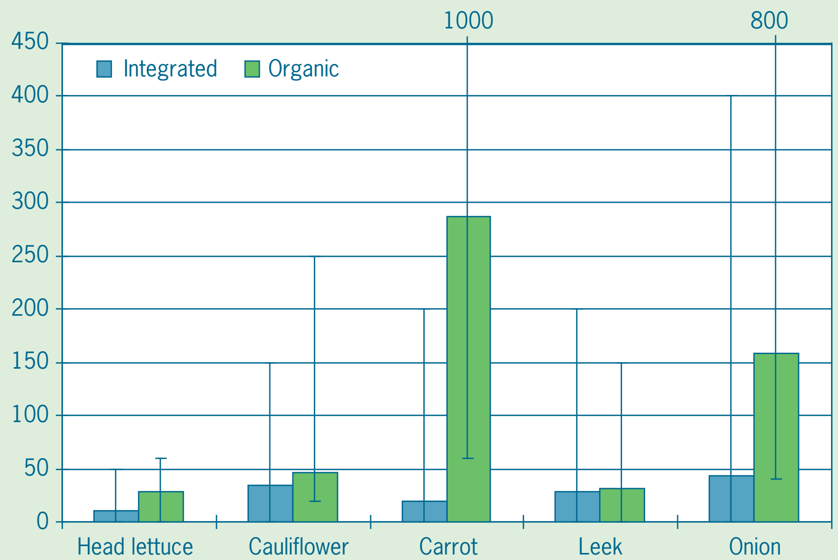

Figure 6.3 Hours of manual weeding per hectare on seven integrated and organic Swiss pilot farms in 1997 on average for normal weed pressure and the maximum for high weed pressure

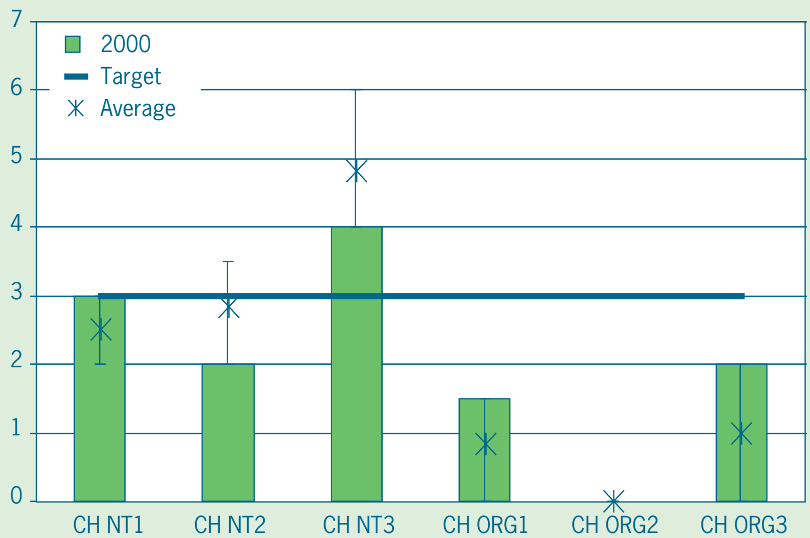

*Figure 6.4 Number of treatments for cauliflower 2000 and its variation 1998-2000 at six Swiss pilot farms (including treatments with **Bacillus thuringiensis**)*

Table 6.10 presents the actual values of the parameters from six integrated and organic Swiss pilot farms. The organic farms applied a lower number of treatments on most vegetable crops compared to the integrated farms. The number of treatments that can be included in an optimal crop protection strategy depends on the pest and disease pressure at a site in the particular year and the quality requirements of the particular market. The integrated farm in the Seeland region CH INT3 had the highest shortfall among all of the crops. Due to high pest and disease pressure in the region, the farmer applied more treatments than is the standard in the Swiss good agricultural practice. Especially, in cauliflower, he used the treatments to prevent infestations by the gall midge, which is an important pest in the Seeland region (Figure 6.4). Contrary to the recommendations and the management of pest resistance to insecticides, the farmer sprayed this crop almost exclusively with one synthetic pyrethroid, which resulted in the lowest input of active ingredients in the year 2000 among the integrated farms and achieved the desired result (Figure 6.5). However, the opposite was true for the farm CH INT3, which was the most problematic concerning pesticide use. This is indicated by the number of treatments. The input of active ingredients alone can lead to wrong con-

clusions as this example shows.
Bacillus thuringiensis compounds were used only at the organic farms to control caterpillars in cauliflower or leek moth in leek. Copper was applied at the integrated and the organic farms to control the very harmful fungi (Oomycetes, *Phytophthora porri*) in leek, downy mildew (*Bremia lactucae*) in lettuce and downy mildew (*Peronospora destructor*) in onion. At present, copper is the only available fungicide for organic farms to control these fungi. Due to higher temperatures and rainfall than normal, for example in the Netherlands, these diseases in Switzerland were more severe and led to higher or even total loss of yield in lettuce and onion crops at the organic and integrated pilot farms. Because the copper use was limited to these crops and diseases, the yearly copper input per ha and per year on average in the Swiss selected crops was low (Figure 6.6). The copper input in the single crops was 50% to 90% lower than the maximum dose of 4 kg ha^{-1} $year^{-1}$ copper allowed. Sulphur was used only at the organic farm CH ORG3 as a additional to copper in amounts of 0.16 to 0.32 kg ha^{-1} $year^{-1}$.

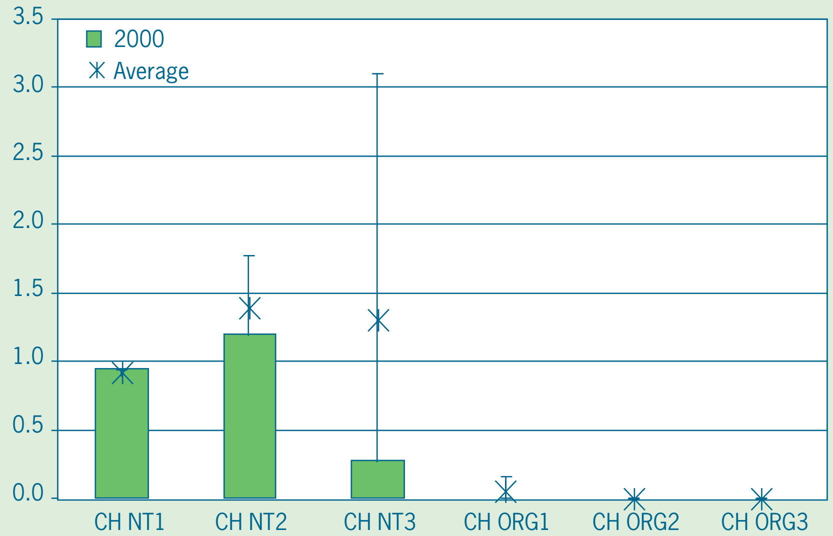

Figure 6.5 Active ingredient input in kg ha^{-1} for cauliflower 2000 and its variation 1998-2000 at six Swiss pilot farms (excluding Bacillus thuringiensis compounds)

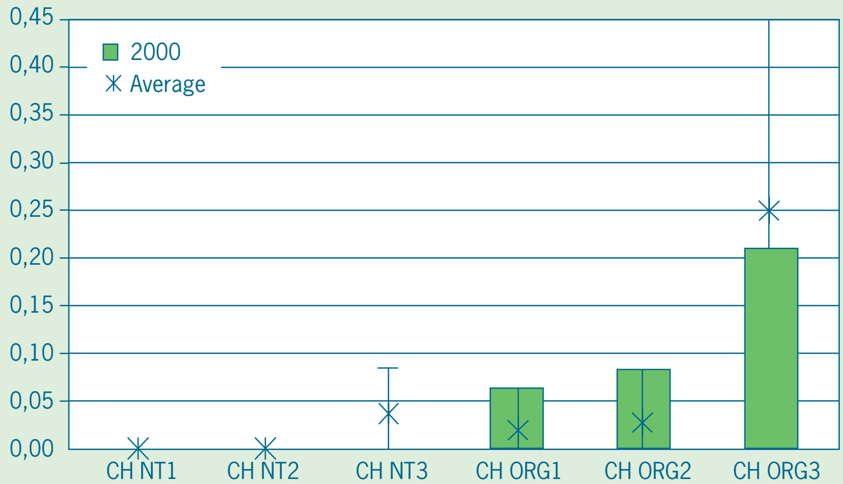

Figure 6.6 Copper input in kg a.i. ha^{-1} and year on average for the selected crops 2000 and variation 1998-2000 on six Swiss pilot farms

Table 6.10 Actual values for parameters related to pesticide use and emissions at three pairs of integrated and organic Swiss pilot farms 1998-2000

system	year	number of crops	Swiss target in number of treatments, sum over all crops[1]	number of treatments, sum over all crops[2]	number of treatments per crop	kg a.i. ha^{-1}, sum over all crops[2]	kg a.i. ha^{-1} per crop[3]
CH INT1	1998	4	23	11.5	2.9	2.92	0.73
	1999	4	23	9.5	2.4	6.42	1.61
	2000	4	23	17.5	4.4	8.84	2.21
CH INT2	1998	5	27	16.5	3.3	12.86	2.57
	1999	5	27	12.5	2.5	10.31	2.06
	2000	5	27	12.0	2.4	11.49	2.30
CH INT3	1998	3	14	21.0	7.0	7.46	2.49
	1999	3	14	20.0	6.7	8.91	2.97
	2000	3	14	12.5	4.2	5.19	1.73
CH ORG1	1998	4	23	4.5	1.1	0.85	0.21
	1999	4	23	3.0	0.8	0.50	0.13
	2000	4	23	7.5	1.9	0.91	0.23
CH ORG2	1998	5	27	0	0	0	0
	1999	5	27	0	0	0	0
	2000	5	27	1.0	0.2	0.40	0.08
CH ORG3	1998	5	27	4.5	0.9	1.04	0.21
	1999	5	27	6.0	1.2	2.49	0.50
	2000	5	27	6.0	1.2	1.49	0.30

1. Swiss targets for selection of crops: 4 treatments for lettuce, 3 treatments for cauliflower, 7 treatments for leek, 9 treatments for onion, 4 treatments for carrots (INT1 and ORG1 had lettuce, cauliflower, leek, onion; INT3 had lettuce, cauliflower and leek)
2. the average is for two lettuce and two cauliflower crops, for leek, onion and carrot the value is for one crop each. All treatments were counted: synthetic and non-synthetic (natural) pesticides, copper and sulphur, B.t.
3. the amount of a.i. include all synthetic pesticides, copper and sulphur, B.t. compounds are excluded

7 General discussion

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7.1 Introduction

Conventional vegetable farming uses high input of pesticides to protect crops against pests and diseases because the financial risks are great. Current quality standards required by markets are very high. Farmers try to achieve maximum quality and prevent quality degradation or even total rejection of crops because input costs (planting material and labour) are high. Preventing the spots or aphids on the produce requires a lot of effort and (pesticide) input, so it is understandable that pesticides are applied preventively to lower risks.

Nowadays this one-sided approach is believed to be not sustainable. Society demands another way of agriculture that is not longer exclusively based on the use of pesticides. This has lead to the development of integrated and organic farming based on process-integrated methods, instead of end-of-pipe solutions as pesticide use. In the organic and integrated approach, crop protection is an integral part of the total system. A lot of research has already been done to develop more integrated methods in arable farming. In vegetable production, with its large variety of crops and the accompanying noxious organisms, there is still a lack of knowledge.

Reducing pesticide input by using integrated or organic farming methods requires the farmer to have expertise in order to keep financial risks within limits. This is especially important in integrated systems as integrated produce has the same price as conventionally grown produce. Organic produce has significantly higher prices than conventionally grown produce. The higher revenues normally compensate sufficiently for the extra costs and usually the unavoidable loss of production.

In the next paragraphs the results, bottlenecks and possibilities of integrated crop protection are discussed. First the results in terms of quality production and pesticide use and emission are mentioned. The second part discusses the additional knowledge that needs to be gained The chapter is closed with a discussion about the knowledge transfer to practice as a necessary follow up.

7.2 Testing and improving in VEGINECO

7.2.1 Evaluation of pesticide use

Pesticide use was evaluated on the input of active ingredients and their potential emission to the environment, except in Switzerland where pesticide use was evaluated on the number of treatments. Obviously, the effect on the environment from pesticides use in organic systems was in all cases much lower than in the integrated systems. Analogous, organic farms in Switzerland applied a lower number of treatments on most vegetable crops compared to integrated farms. However, the quality requirements and the crop protection strategies for organic vegetables have gradually been adjusted to integrated standards since wholesale distributors started selling organic produce. This means that the difference between organic and integrated farms in number of treatments is becoming smaller.

Integrated systems
In general, the integrated systems greatly reduced pesticide input and emissions in comparison with average practice. All emission targets were met in all systems except for the emissions to groundwater (target value of 0.5 ppb derived from European legislation) in some integrated systems in Italy and Spain. Selection of active ingredients and lower frequency of treatments have contributed to the decreased effect of pesticides on environment in the tested systems.

Bacillus thuringiensis (B.t.) compounds were used in integrated systems in Switzerland, Spain and Italy. However, Bt was not used in the Netherlands, as Bt was considered ineffective. In comparison, the use of ***Bacillus thuringiensis*** and ***azadiractin*** was very important in Spain for minimising the environmental impact of insecticides and to preserve the equilibrium within the farming systems. The alternation of these two compounds can eliminate the appearance of pesticide resistance.

In the systems in the Netherlands, the group of pesticides with the highest input was the fungicides, and herbicide input was the lowest. In Spain and Italy, the highest input of pesticides in 2000 was due to herbicides, followed by insecticides or fungicides, depending on the farming system. This is different from conventional use within Europe where fungicides are the most important followed by herbicides (see section 2.1). Although, pesticide input can vary greatly from year to year or system-to-system, this reflects the main problems in the corresponding systems: fungi diseases in the Netherlands and weeds in Spain and Italy. The last problem is mainly caused by the lack of practical alternatives to herbicides (an alternative for ***lenacil*** in I INT1 and an acceptable herbicide for fennel in Spain).

In the Spanish systems, the amount of active ingredient applied depends on the amount of spraying solution used per hectare (different per system) as the dosage of pesticides and fungicides is usually per litre of spraying solution (concentration). In this case, improved application techniques and tuning of pesticide doses are very important to minimise the environmental impact and improve the effectiveness on pests and diseases.

Organic systems

The target values set for the pesticide parameters were fulfilled in all cases. However, it must be noted that some pesticides, authorised in organic farming, have an environmental impact such as copper, ***metaldehyde***, and bio-pesticides (***azadiractin*** or ***rotenone***). Because of this, no pesticides were used in the Dutch system at all.

On the other hand, bio-pesticides allowed by the European legislation were commonly applied in Italy and Spain. Copper is used in Switzerland, Spain and Italy because it is the only available fungicide available for organic farms to control very harmful fungi such as the downy mildew in onion. Although the efficiency is sometimes questionable, copper use is believed to be inevitable in organic farming without causing severe yield reductions in Switzerland, Spain and Italy. The copper input at a crop level was in all cases 50% to 90% lower than the maximum dose of 4 kg copper ha-1 year-1 allowed.

7.2.2 Influence of pest and disease control on production quality and quantity

Insight in integrated control strategies improved during the project. Better use of threshold values and timing of treatments reduced pesticide input while quality and yield were not negatively influenced. Results from organic control strategies could often be used to improve integrated control strategies. Regular field inspection for the presence of pests and diseases and weed pressure is very important.

The effects of the individual measures are hard to assess in a total farm approach. The total complex of measures is supposed to lead to reaching the objectives of the system. Furthermore, structural measures as crop rotation and agro-ecological layout mostly have a long-term effect that exceeds the four-year project period. The effect of the total set of measures is judged by the level of production quantity and quality and by the amount of inputs and losses on system level.
The effects of preventive measures such as the use of hedgerows as shelters for natural predators, or the use of crop rotation have been hardly evaluated. However, the presence of natural predators in the different species of the hedgerows was checked in two of the Spanish systems (see country chapter). The evaluation of the effect of crop rotation on soil borne diseases was not possible in only four years. Unfavourable weather conditions or bad irrigation management mainly caused the occurrence of soil born diseases. In other crops such as artichoke in Spain, crop rotation is considered a solution for the long-term. For short-term solutions, solarisation and bio-fumigation instead of chemical disinfection have proved to be effective enough.

The interaction between adjacent crops in time and space was positive in certain situations in Italy and Spain. The layout made it possible for natural predators, which were well established in advanced crops, to reach easily the adjacent ones that were in earlier stages of development. The development of certain pests (for example, afidiidae from cauliflower to lettuce) was largely inhibited.

When possible, resistant or tolerant varieties against pests and diseases were used in organic and integrated systems. Although some problems (N. ribisnigris in lettuce or late blight in potato) were solved, this did not happen in all cases. Resistance to downy mildew was broken in lettuce in all countries and other viruses seriously affected the tomato variety with resistance to TSWV. In addition, the crop cycles were adapted to periods with lower pest and disease pressure successfully in Italy, the Netherlands and Spain.

In some cases, releases of natural predators resulted in good biological control (for example, Phitoseiulus persimilis to control the Red spider in melon and strawberry in Italy). Another remarkable strategy was the use of ducks to control slugs in Italy and the Netherlands. In the future, testing releases of natural predators against lepidoptera, one of the most important pests in vegetables, could be very interesting.

The effectiveness of copper and potassium phosphates as fungicides in Spain was difficult in some cases, depending on the weather conditions and the incidence level of the disease. Sulphur, in comparison, was always very effective controlling powdery mildew in watermelon and pepper.

The use of insect nets in certain crops to delay or stop the pests from reaching the crop was successful (tomato and autumn lettuce in Spain). However, management was difficult in some cases. Insect nets are difficult to combine with split dose fertilisation systems and mechanical weed control, as the nets have to be removed for every treatment. Diseases, mainly fungi, were generally responsible for the largest losses in yield in the VEGINECO systems. In addition, viruses damaged some crops in certain periods in Spain.

Integrated systems

In general, the large reduction of pesticide input and emission did not have a negative influence on costs, labour and quality production. However, some vulnerable crops had serious problems with decreases in yield. Examples are lettuce in Italy and Spain because of *Bremia lactucae*, celery in Italy because of *Septoria apiicola* and onion in Switzerland because of downy mildew. In the Netherlands, the applied integrated strategies for Brussels sprouts focussed too much on their environmental consequences and too little on quality production. In the cases of lettuce in Spain and celery in Italy, the authorised fungicides were not sufficiently effective. In these cases, the high risk of decrease in yield in vegetable crops caused by pests and diseases was confirmed. In Spain, 85% of treatments for pests were carried out to control caterpillars, 10% were carried to control aphids and spider mite. The remaining pests threatened the crops minimally.

Organic systems
Organic production levels (quantity and quality) were only considerably lower than conventional production in the Netherlands. In Switzerland, the reduction was only about 5% in quantity and 0% for quality. In Spain, the reduction was about 10% in quantity and 1% in quality. In Italy, the quantity and quality produced in the organic system were better than in the integrated system (I INT2). In the Netherlands, pests and diseases largely caused the decrease in quality and quantity, although, the use of available authorised bio-pesticides would not have improved production sufficiently. For vulnerable crops such as Brussels sprouts and potatoes, prevention and control strategies are not satisfactory for a stable and sufficient quality production. Progress could be made with major breakthroughs in the availability of resistant varieties. Although hazards did occur in the organic systems in Switzerland, Spain and Italy, they were hardly more frequent than in the integrated systems. It was not in all cases clear (in case of direct farm sales) whether the quality standards for organic products were exactly the same as for integrated or conventional production.

7.2.3 Weed control

Probably the most important preventive measure for weed control in both organic and integrated systems is making a clean start at sowing or planting. Most weeding is done to prevent weeds setting seeds as this is more important than risk of competition and loss in yield. Only in the Netherlands, the crop rotation designed took into account the prevention of weeds (see Chapter 3 and the Manual on Prototyping Methodology and Multifunctional Crop Rotation).

Weed control is carried out very differently amongst the countries. In Netherlands and Switzerland, mechanical control was more widely utilised than in Italy and Spain. Fields are smaller and the available machinery and tools are not as appropriate in Italy and Spain. For instance, complete mechanical control was possible in all the planted crops in the Netherlands. Only when weather conditions were bad, chemical correction was sometimes necessary. On the other hand, the drip irrigation in the Spanish systems made mechanical weeding difficult because weeds grew mainly in the crop rows, where the irrigation equipment was installed. The mechanical weeding equipment could not work within the crop rows very well. In addition, false sowings were not successful because it was difficult to wet the entire field with the drip irrigation system.

The use of black plastic mulch was the main alternative for herbicides in the Spanish and Italian integrated systems. However, the massive use of plastics can also be very harmful for the environment, especially when recycling is not possible. New biodegradable materials eliminate this disadvantage, however they are more expensive.

In some systems, the timing of mechanical and manual weeding was sometimes insufficient, considerably increasing the amount of manual labour needed. Probably, farmers do not pay sufficient attention to weed control. When herbicides are not used, the risk of seeding weeds is higher. This can lead to an increased weed infestation in the fields.

Integrated systems
In the Netherlands, basic mechanical control with a minimal amount of herbicide (low dose techniques) input in some crops reduced the amount of work on the farm, including the amount of manual weeding. Developments in mechanical weed control are ongoing and in the future, in good conditions, complete mechanical control should be possible for all planted crops. However, in emergencies, a backup of chemical solutions with low emissions will improve the stability of the strategy.

In Italy and Spain, where dependency on chemical control is greater, authorised herbicides (mainly soil herbicides) for certain crops had a high impact on the environment. Therefore, weed control was the largest environmental problem in the integrated strategies. On the other hand, no proper authorised herbicides were available for some crops. In these cases, many hours of manual weeding (for example, fennel in Spain) were necessary. The localised use of herbicides (spot-wise or band spray) when the level of weeds was medium or low had good results with a minimum of herbicide use.

Organic systems
In organic weed control, input of herbicides is forbidden so mechanical and manual weed control is necessary. The manual labour for weed control was, under the current circumstances, acceptable in the Netherlands. With the expected increasing costs and decreasing availability of labour in the near future, the amount of manual weeding must decrease. In addition to improving organic production, the research has also proved to be a driving force for improvements and developments in weed control strategies. However, in Switzerland, crops like carrot and onion required ten times more hours of manual weeding at the organic farms than at the integrated farms, where herbicides are normally used. In general, weed pressure was higher in crops grown on organic soils and required more hours of manual labour than on mineral soils.
In Italy, weed control was carried out using specific machinery and a burner. The burner was used on the

entire field before planting or sowing to obtain a clean sowing bed and to control weeds in the pre-emergent stage in green beans and for the control in between rows in strawberry of *Portulaca sp*. New research is necessary to improve mechanical weed control and to reduce manual labour costs.

In the Spanish organic system, as in the integrated systems, the main aspect to improve is weed management. Although the current prices of organic produce can bear the high costs of manual weeding, it is necessary to adopt new control techniques due to probable changes in market trends. In the Valencian conditions, the organic, field-grown vegetables can be an appropriate alternative for the continuity of these traditional crops because of the small fields and traditional farming.

7.3 Theoretical shortcomings

Although integrated and ecological crop protection strategies (I/ECP) were applied in all the partners' systems and control strategies greatly improved, many problems need to be overcome and gaps in knowledge need to be filled in. One difficulty is that high level of expertise is needed in order to carry out integrated and ecological strategies adequately. A thorough knowledge is necessary concerning pest and disease symptoms, recognition of harmful organisms, damage thresholds, pesticide availability and properties, and accurate weather forecasts and warning systems.

In addition, market globalisation can greatly influence the spread of different diseases and pests, making the established strategies useless. Finally, the appearance of new pathogens is becoming much faster than previously, and vegetable crops are being especially affected. Research is needed to define control strategies for these new pests and diseases.

There is a real lack of knowledge concerning the influence of crop rotation on crop protection. There is very little known about the interactions between crops in a rotation and even the effect of a specific rotation on pests and diseases. Farmers are usually insufficiently aware of the concept of crop rotation and have too little experience with its benefits. Most of the 'integrated guidelines' describe crop rotation for the sustainability in farming systems vaguely, only recommending or suggesting its practice. Crop rotation must be the key to solve most of the soil-born diseases in the middle and long-term. Crop rotation, as central part of agronomy and of crop health more specifically, has become less significant in farming technology in the last few years. For optimal crop protection with minimum negative impact on the environment, crop rotation should be introduced again (see Manual on Prototyping Methodology and Multifunctional Crop Rotation).

There is also a lack of information about the effect on crop protection of on-farm nature management. Hedgerows and grass strips form shelters for different natural predators. The optimal composition of hedgerows or grass strips that is the most beneficial to the natural predators is unknown. In addition, the optimum size of fields and buffer zones, and the maximum distance between elements and minimum connectivity are also unknown. In addition to contributing to crop protection, buffer zones can add to a more attractive countryside and increase biodiversity. The use of resistant or tolerant varieties can be a very powerful instrument in the control or prevention of damage of pests and diseases. However breeding of varieties for vegetable crops has been focussed very much on production and quality. Only in those situations were there is no sufficient chemical strategy to control specific pests or diseases, plantbreeders has often managed to produce resistant varieties (for example against viral diseases). In case of an available and sufficient chemical strategy the effort of focussed breeding for resistance to a specific pest or disease, has not been worthwhile for breeding companies. Also the variety choice of farmers is focussed on quantity and quality instead of disease resistance. The use of a variety with a few percents higher yield combined with the use of pesticides was economical preferable over the use of a resistant variety with a somewhat lower yield. Moreover partial resistance is often not acceptable or sufficient (contrary to arable crops) because of the nature of the product (often leaves) and the market demands for spotless products. Hopefully the interest in resistance breeding will get a boost now organic agriculture is growing and the availability of effective pesticides for vegetables is decreasing. Incentives from policy would be welcome to strengthen this development.

The 'European list of pesticides' (European harmonisation) will probably limit the possibilities for pesticide choice. It is expected that insufficient pesticides will be available for crops with relatively small areas like vegetables. This is already reality for some crops. The development of new, effective, safe and low emitting pesticides specific for vegetable crops is in most case not cost effective for the chemical industry. The situation of or a very small package of admitted pesticides for vegetable crops, tends to work contra productive. Farmers are more and more forced to turn to illegal use of pesticides that are allowed in arable crops. Moreover the one sided use of a single pesticide has a risk of leading to resistance development in the pathogen. So in vegetable crops, there is still a need for a set of safe, effective and low-emitting pesticides. Solutions have to be found to ensure the availability of these pesticides in the future. These pesticides are to be used as an emergency solution and not as starting point for the crop protection strategy.

7.4 Application in practice

Often I/ECP strategies may still appear to be unmanageable for the farmers because some tasks or even the whole strategy is too complicated (expertise is lacking), practical experience is missing (how to handle and adjust a new machine) or the risk of a strategy is estimated to be too high. In other circumstances, farmers may not accept bio-pesticides or new 'light' techniques because of a lack of confidence in the effectiveness.

In the Netherlands, Italy and Spain, the established strategies were executed on a semi-practical scale, and there are some limitations in the experimental setting used. In this case, researchers were allowed to take greater risks than an average farmer can take. Moreover, testing is done under a limited set of circumstances and the manageability of strategies is sometimes difficult to assess. For these reasons in the case of the Netherlands, an important next step would be to test and improve the strategies on a number of working farms.

In Switzerland, the strategies were already applied on commercial farms. The majority of the farmers found that the available monitoring methods and threshold concepts are still too complicated and too time-consuming. Farmers do not accept too many risks and cannot use too much time for extra ecological activities, if they want to stay in business.

Therefore, as discussed in the previous chapter, it is vital to translate these integrated methods into simple management tools.

In practice, field inspection of the presence or absence of pests and diseases is the most common threshold method. Farmers should carry out these inspections because the technicians usually cannot inspect every farm as often as needed. This means that, on the one hand, the strategies have to be as simple and manageable as possible. On the other hand, expertise is necessary for not only extensionists and technicians, but for farmers also. Applied research and extensionists working together with groups of farmers can play an important role in testing, improving and disseminating farming methods. In this way, farmers can also become more confident in the new techniques.

The conversion to "real integrated farming" in certain conditions could even require a transition time as in organic farming because not all farms are prepared or have the conditions to practice real integrated production.

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VEGINECO publication list

VEGINECO project reports

1. VEGINECO Final Report
W. Sukkel and A. Garcia (Eds.)
VEGINECO Report 1. 2002. Applied Plant Research. Lelystad.

2. Manual on Prototyping Methodology and Multifunctional Crop Rotation
J.J. de Haan and A. Garcia (Eds.)
VEGINECO Report 2. 2002. Applied Plant Research. Lelystad.

3. Integrated and Ecological Nutrient Management
J.J. de Haan (Ed.)
VEGINECO Report 3. 2002. Applied Plant Research. Lelystad.

4. Integrated and Ecological Crop Protection
W. Sukkel and A. Garcia (Eds.)
VEGINECO Report 4. 2002. Applied Plant Research. Lelystad.

5. Ecological Infrastructure Management
G.K. Hopster and A.J. Visser (Eds.)
VEGINECO Report 5. 2002. Applied Plant Research. Lelystad.

6. Proceedings of the VEGINECO workshop, 20-21 June 2001, Amsterdam
W. Sukkel and J.J. de Haan (Eds.)
VEGINECO Report 6. 2002. Applied Plant Research. Lelystad.

Other project-wide VEGINECO publications

Wijnands, F.G. and W. Sukkel. 2000. Prototyping organic vegetable farming systems under different European conditions. In Proceedings 13th IFOAM Scientific Conference, 28-31 August Basel. vdf Hochschulverlag. Zürich. pag. 202-205.

In addition, every partner has published many publications in national and regional agricultural journals. For a complete overview, contact the concerning partner.

Annex 1. Short description of the systems

Southwest region of the Netherlands

Regional Context

In the Netherlands, approximately 70 000 hectares of more than 50 different types of vegetables are grown (including onion and peas). The farms are be divided in two groups: 1) the very specialised, small farms that grow mainly fresh market vegetables (19 000 ha, 4 200 farms, average size 4.5 ha) and 2) the larger farms with arable activities (more industrial processing crops, 25 000 hectares of vegetables, 4 900 farms, 25-75 hectares per farm). Arable farms are increasingly including vegetables in their crop rotations. In addition, farm size and specialisation is growing and land lease and exchange is becoming more important. The most important crops in terms of area and financial turnover are onions, carrots, chicory, leek, asparagus, Brussels sprouts, cauliflower, cabbage, lettuce, beans and peas.

Site information

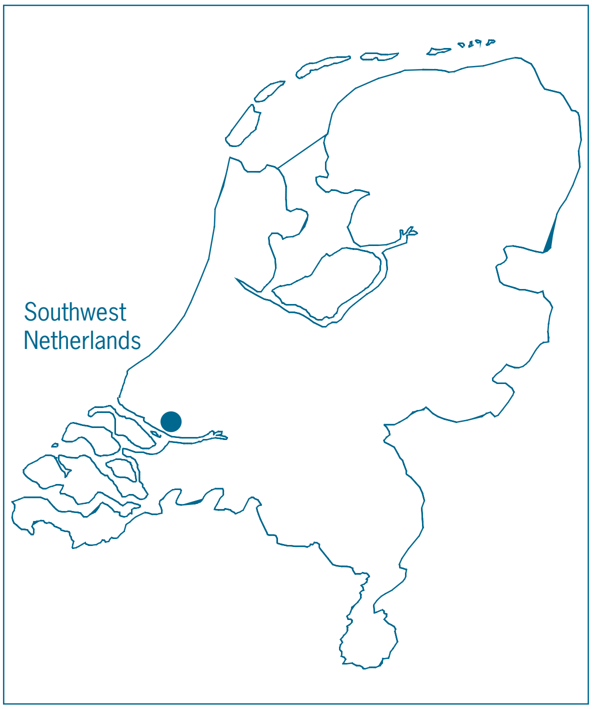
Soil characteristics	Integrated	Organic
main soil type	marine clay	marine clay
clay (%)	33	33
organic matter (%)	2.4	2.2
pH (KCl)	7.5	7.2

Climatic information	
annual average precipitation	760 mm
annual average sunshine	1 450 hours
annual average radiation	380 kJ cm^{-2}
annual average temperature	9.9 °C
average latitude	51 °N.
average altitude	0.8 m above sea level

Tested systems

In the Netherlands, two integrated and one organic systems were tested on an experimental location in the Southwest region of the Netherlands. A combination of vegetables and arable crops were chosen in all systems, this represented the developments in the region. The labour demand differed between the two integrated systems. The system with Brussels sprouts (NL INT1) as the main crop was designed as a labour extensive system. The other system, with iceberg lettuce (NL INT2) as main crop, was designed as labour intensive.

Location



Rotations

Integrated fresh market Brussels Sprouts (labour extensive) (NL INT1)	Integrated fresh market Iceberg Lettuce (labour intensive) (NL INT2)	Organic fresh market system (NL ORG)
1. potatoes	1. potatoes	1. iceberg lettuce
2. Brussels sprouts	2. fennel / celeriac / cauliflower	2. cereal / clover
3. winter wheat / spring barley	3. winter wheat / spring barley	3. Brussels sprouts
4. fennel / celeriac / iceberg lettuce	4. iceberg lettuce	4. fennel
		5. cereal / clover
		6. potato

Emilia-Romagna, Italy

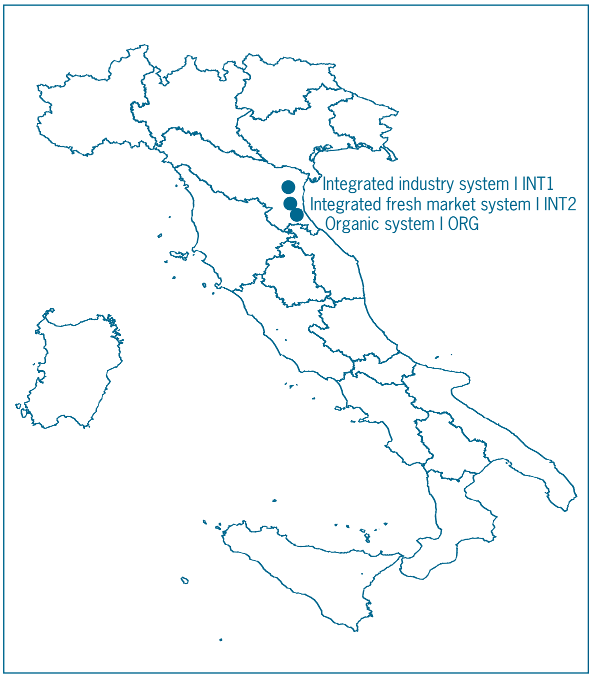
Regional context

In Emilia-Romagna, Italy, there are almost 4 000 specialised farms and 35 000 non-specialised farms in vegetable farming. Some 54 000 hectares are cultivated with vegetables at medium and large sized farms (5-20 ha). The main crops grown on large farms for industrial processing are tomatoes, green beans, (water)melons and onions. These farms have a high level of mechanisation. At small farms (2-5 ha), the main crops are grown for the fresh market (lettuce, fennel, spinach, celery, potatoes, melons and cauliflower). These small farms have a low level of mechanisation. Since 1993, integrated vegetable farming have produced crops under Quality Control (QC) labels.

Tested systems

In Emilia-Romagna, two integrated and one organic systems were tested in the eastern part of the region in Ravenna (I INT1) and Cesena (I INT2 and I ORG). I INT1 is focussed on industrial vegetable crops in combination with arable crops while I INT2 and I ORG are focussed on fresh market vegetables.

Location



Site information

Soil characteristics	I INT1	I INT2	I ORG
soil type	silt loam	silt clay	silt clay loam
% clay	20	42	35
% silt	63	47	53
% sand	17	12	12
% organic matter	1.2	1.8	2.7
pH (H_2O)	7.8	7.7	8.0
Climatic information	RAVENNA (I INT1)		CESENA (I INT2 and I ORG)
annual average precipitation	581 mm ('88-'94)		591 mm ('92-'94)
annual average sunshine	4.139 hour		4.139 hour
annual average radiation	439 kJ cm^{-2}		541 kJ cm^{-2}
annual average temperature	13.1 °C		13.9 °C
average latitude	44-45 °N.		44 °N.
average altitude	5 m above sea level		16 m above sea level

Rotation

Integrated industry system (I INT1)	Integrated fresh market system (I INT2)	Organic fresh market system (I ORG)
1. spinach	1. lettuce spr./sum./aut.	1. green beans
tomato	catch crop	fennel
2. wheat	2. green beans	2. melon
green beans		
3. sugar beet	3. strawberry	3. catch crop
catch crop	celery + catch crop	
4. melon	4. melon	4. strawberry
		lettuce summer + autumn

Valencian Community, Spain

Regional context

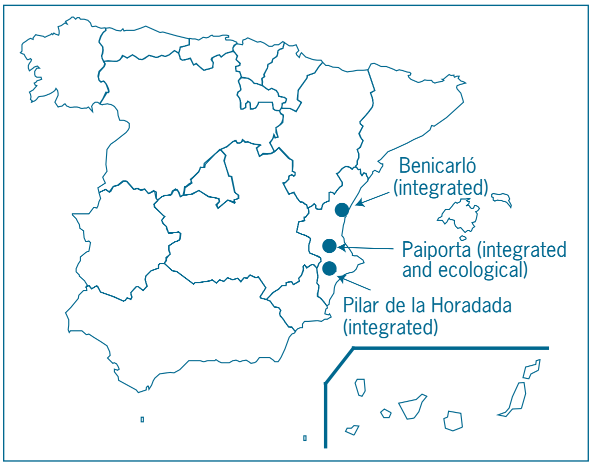
In Valencia Region, Spain, an area of about 44 000 hectares are grown each year with more than 30 vegetable crops (including potato). The most important crops are tomato, onions, potato, artichoke, watermelon and cauliflower. Most of the vegetables are grown for fresh market production. The farms are small (more than 50% of the farms have a surface area less than three ha, and about 20% of the farms have a surface area less than one ha). Levels of mechanisation are generally low. Irrigation is necessary because of the dry conditions and low natural rainfall. Crops can be grown all year round.

In Spain, the area cultivated for organic farming was about 150 000 hectares (less than 1% of the agricultural area). In Valencia, the area with organic farming is about 3 000 ha, with about 3% area for vegetable crops.

Tested systems

In the Valencian region, three integrated and one organic systems were tested at different locations. The three integrated systems are representative for their area: Pilar de Horada (ES INT1 in the south of the Valencian Region, Benicarlo (ES INT2) in the north and Paiporta (ES INT3) in the centre. The organic system (ES ORG) is located at the same experimental farm as ES INT3. ES INT1 and ES INT2 are located at private farms, ES INT3 and ES ORG are located at an experimental station.

Location



Site information

Geodesic	co-ordinates	ES INT1	ES INT2	ES INT3 and ES ORG
Situation	Latitude	37° 51' N.	40° 23' N.	39° 28' N.
	Longitude	0° 43' W.	4° 4' E.	0° 25' W.
	Altitude	<50 m above sea level	17 m above sea level	52 m above sea level
Province		Alicante	Castellón	Valencia
Town		Pilar de la Horadada	Benicarló	Paiporta

Soil characteristics		ES INT1	ES INT2	ES INT3 and ES ORG
Soil texture	Sand (%)	23	27	34
	Loam (%)	44	47	49
	Clay (%)	33	26	27
Organic Matter (%)		2.3	2.5	1.8
pH (soil/H_2O 1/5)		8.4	8.1	8.5

Climatic characteristics	Mean temperatures	ES INT1	ES INT2	ES INT3 and ES ORG
Temperature	Max (°C)	26.2	20.7	21.9
	Min (°C)	11.1	10.7	13.2
	Mean (°C)	18.2	16.5	16.7
Average rainfall (mm)		292	482	481

Rotation

Pilar de la Horada integrated (ES INT1) private farm	Benicarlo integrated (ES INT2) private farm	Paiporta integrated (ES INT3) & organic (ES ORG) experimental station
1. vetch-oats pepper + little gem	1. seed artichoke tomato	1. artichoke green bean
2. little gem sweet corn + broccoli	2. green bean lettuce	2. onion + watermelon, cauliflower
3. lettuce onion	3. lettuce watermelon	3. potato fennel
4. celery watermelon	4. cauliflower vetch-barley + artichoke	4. oats seed artichoke

Switzerland

Regional aspects

In Switzerland, an area of 7 700 hectares is grown with open field-grown vegetables and 3 800 hectares with vegetables for industry. In total, it concerns 1 400 farms. Most of the farms grow many different crops. The most important crops are lettuces, cauliflower, carrot, onion, leek, fennel and celeriac. 40% of the national demand for vegetables is imported. Integrated crop production and organic farming is of increasing importance in Switzerland (production under label guidelines). The government intends to convert 90% of the farms to integrated or organic farming within the next ten years. At present, more than 75% of vegetable farms already met the requirements for integrated crop production. An increasing number of farms (5% to 20%) will convert to organic production in the near future. Practical difficulties on organic and integrated vegetable farms mainly concern the following topics: (1) availability of nitrogen, (2) weed control and (3) pests and diseases (Gysi et al., 1996).

Tested systems

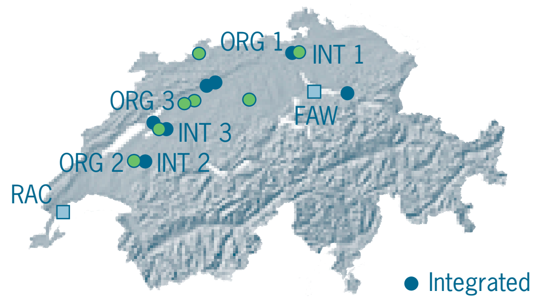
Three integrated and three organic pilot farms were tested:
INT1/ORG1: wholesale distributors, Zurich
INT2/ORG2: direct sale, French-Swiss
INT3/ORG3: retailers / wholesalers, Seeland

Main crops and rotation

Main crops
- head lettuce
- cauliflower
- carrots
- leek
- onions

Rotation length
- short: 3-4 years
- long with arable crops: 6-12 years

Location



Site information

Pedeological information	Bern/Biel		Zürich	
soil type	histosol[2]	eutric cambisol[2]	eutric cambisol[2]	gleyic/calcaric cambisol[2]
clay (%)		1-10/26-54[1]	15-20[2]	30-40[2]
sand (%)		71-94/16-55[1]	40-85[2]	10-70[2]
silt (%		6-19/20-44[1]	0-50[2]	0-50[2]
organic matter (%)	> 30[1]	1-26[1]	2-5[2]	2-5[2]

Climatic information[3]	Bern/Biel	Zürich
annual average precipitation	1 088 mm (Biel)	1 005 mm (Reckenholz)
annual average sunshine	1 681 hour (Liebefeld 95)	1 501 hour (Reckenholz 95)
annual average radiation	4 325 MJ m^{-2} (Liebefeld 95)	3 858 MJ m^{-2} (Reckenholz 95)
annual average temperature	8.5 °C (Biel)	7.8 °C (Reckenholz)
average latitude	47° 00' N.	47° 30' N.
average altitude	440 m above sea level	450 m above sea level

References:
[1] Organische Böden des schweizerischen Mittellandes, Presler/Gysi 1989
[2] Bodeneignungskarte der Schweiz 1980
[3] Annalen der Schweizerischen Meteorologischen Anstalt 1995

Annex 2. Definitions of parameters

Parameters	Definition	Target
Quality production		
1. Quantity of produce (QNP)	The extent to which good regional yield is realised. QNP = realised yield (kg ha^{-1}) divided by good regional yield (kg ha^{-1}).	All crops should have a yield equal to or higher than good regional yields. QNP ≥ 1
2. Quality of produce (QLP)	The extent to which regional good quality is realised. QLP = realised amount in quality class 1 divided by regional good amount of quality class 1.	All crops should have a quality equal to or higher than regional good quality. QLP ≥ 1
3. NO_3^- content of crop produce (NCONT)	The nitrate content in leafy vegetables in mg kg^{-1} fresh matter.	All leafy crops should have a lower NCONT than the national standard. NCONT < x ppm
Clean environment nutrients		
4. Phosphate Annual Balance (PAB) 5. Potash Annual Balance (KAB)	Phosphate and Potash Annual Balances (PAB/KAB) are phosphate (P_2O_5) and potash (K_2O) inputs divided by phosphate and potash off-take with crop produce in one year.	The value of the target is dependent on the value of the soil reserves (PAR/KAR) (see 13,14) • PAB/KAB > 1 when PAR/KAR is below desired range • PAB/KAB = 1 when PAR/KAR is in desired range • PAB/KAB < 1 when PAR/KAR is beyond desired range
6. Nitrogen Available Reserves (NAR)	Mineral Nitrogen Reserves (NAR) in the soil (0-100 cm) at the start of the leaching season (kg ha^{-1}).	The target values are set such that the EU-norm for drinking water (50 mg NO_3^- l^{-1}) should not be exceeded. NAR < x kg ha^{-1} x = 45 kg ha^{-1} on sandy soils x = 70 kg ha^{-1} for clay soils
Clean environment pesticides		
7. Synthetic pesticides input active ingredients (PESTAS-Synth)	Pesticide input of synthetic pesticides in kg ha^{-1} active ingredient per year.	The use of pesticides in kg active ingredient ha^{-1} should be as low as reasonably possible. PESTAS-Synth < x kg a.i. ha^{-1}
8. Copper input active ingredients (PESTAS-Cu)	Copper input in pesticides in kg ha^{-1} per year.	The use of copper in kg ha^{-1} should be as low as reasonably possible. PESTAS-Cu < x kg a.i. ha^{-1}
Environment Exposure to Pesticides 9. EEP-air, 10.EEP-groundwater, 11.EEP-soil	Emission potential of pesticide active ingredients (a.i.) to the environmental compartments: • air (kg ha^{-1}) • groundwater ppb • soil (kg days ha^{-1})	The potential emission of pesticides should be as low as reasonably possible or fulfil legal standards (EU directive on drinking water) • EEP-air < x kg a.i. ha^{-1} • EEP-groundwater < 0.5 ppb in total and 0.1 ppb per pesticide (EU countries) • EEP-soil < x kg days ha^{-1}

Parameters	Definition	Target
Nature and landscape		
12. Ecological Infrastructure (EI)	EI is the part of the farm laid out and managed as a network of linear and non-linear habitats and corridors for wild flora and fauna, including buffer strips.	Area with ecological infrastructure should be at least 5% of total farm area EI > 5%
Sustainable use of resources		
13. Phosphorus Available Reserves (PAR) 14. Potassium Available Reserves (KAR)	Phosphate and potash plant available reserves in the soil (kg per unit soil).	PAR/KAR should be within a range that is agronomically desired and environmentally acceptable: $x_p < PAR < y_p$ $x_k < KAR < y_k$
15. Organic Matter Annual Balance (OMAB)	OMAB is the proportion between annual input and annual output (respiration, erosion) of effective organic matter.	The target value is dependent on the actual and desired level of the organic matter content: • OMAB > 1 when actual organic matter content is lower than desired level • OMAB = 1 when actual organic matter content is equal to desired level • OMAB < 1 when actual organic matter content is higher than desired level
Energy Input (ENIN)	Input of direct and indirect (fossil) energy in MJ ha^{-1} used for crop cultivation.	No target established
Farm Continuity		
16. Net Surplus (NS)	Difference between total revenues and total costs (including labour) in € per ha.	Gross revenues should be larger than total costs. NS ≥ € 0
Hours hand weeding (HHW)	The amount of hours needed for hand weeding per ha as indicator of the success of the mechanical and/or chemical weed control.	Hours hand weeding should be as low as possible. HHW < x hours ha^{-1}

Annex 3. Short description of the multi-objective farming methods

Multifunctional Crop Rotation (MCR)
MCR is the major method used to preserve soil fertility and crop vitality in biological, physical and chemical terms. It is also used to sustain quality of production with a minimum of inputs (pesticides, manual and machine labour, fertiliser and support energy).

In MCR, crops are selected and put in order to get maximal positive interaction and minimal external effects for all objectives. A well-balanced mix of crops needs to be chosen. Crops are characterised in their potential role according to different characteristics. Crops are divided into main crops (important from a financial perspective), secondary crops and tertiary crops (the defenders, which put the main crops in an optimal position and defend the rotation against pests and diseases). In addition, an optimal agro-ecological layout of the system in time and space needs to be made to ensure a maximum contribution of the MCR in preventing pests and diseases. MCR forms the basis for the other methods.

Integrated/Ecological Nutrient Management (I/ENM)
I/ENM gives directions in supplying nutrients in the correct amounts and forms, and at the correct time to achieve optimal quality of production; minimise losses to the environment; and keep soil reserves of nutrients and organic matter at adequate levels, agronomically as well as environmentally.

Attention is mainly paid to the macronutrients nitrogen, phosphorus and potassium. Nitrogen, a very mobile nutrient, is treated at a crop level. Phosphorus and potassium are treated at a rotation level as these nutrients are less mobile.

To reach these objectives, the nutrient requirements of the rotation are defined first. Secondly, the contribution of non-fertilisation sources is estimated. External, non-fertilisation sources are deposition, irrigation water and fixation. Internal, non-fertilisation sources (only nitrogen) are green manure, catch crops, crop residues and mineralisation from organic matter in the soil. If these sources are known, the need for fertilisers can be determined. Fertiliser input can be minimised by choosing the correct timing, application technique and fertiliser type.

Integrated/Ecological Crop Protection (I/ECP)
I/ECP supports the Multifunctional Crop Rotation and Ecological Infrastructure Management in achieving optimal quality of production by selectively controlling residual and harmful species with minimal exposure of the environment to pesticides.
The general strategy consists of three steps:

1. maximum emphasis on prevention (resistant varieties, cultural practiceds such as adapting the sowing date and row spacing),
2. a correct interpretation of the need of control (guided control systems, thresholds, signalling systems),
3. the use of all available non-chemical control measures (mechanical weed control, genetic, physical and biological control).

Pesticides are then only necessary as additional measures. Methods with minimum use such as seed treatment, and row or spot-wise application are preferred over applying to the entire field. Appropriate dosages and, when possible, a curative approach (field and year specific), further reduces the input. Finally, pesticides should be carefully selected with respect to selectivity and exposure of the environment to pesticides (EEP).

Minimum Soil Cultivation (MSC)
MSC is an additional method to MCR and I/ENM that sustains quality of production by preparing seedbeds, controlling weeds, incorporating crop residues and restoring physical soil fertility reduced by compaction from machines, specifically at harvest. Soil cultivation should be minimal in order to achieve the objectives with respect to energy use; to maintain sufficient soil cover as basis for erosion prevention; shelter for natural enemies; landscape/nature values; and maintenance of an appropriate organic matter annual balance.

Ecological Infrastructure Management (EIM)
EIM supports MCR in achieving optimal quality of production by providing airborne and semi-soil-born beneficials a place to survive unfavourable conditions, and then recover and disperse in the growing season. In addition, EIM should met the nature/landscape objectives.
Operating EIM implies establishing an area of linear and non-linear elements to obtain spatial and temporal continuity in nature area; and establishing buffer strips to protect these natural areas. Finally, establishing a plan for the long term considering the target species/communities and special ecological elements such as ponds and hay stacks.

Farm Structure Optimisation (FSO)
FSO determines the minimum amounts of labour and capital goods needed to achieve the required net surplus (all revenues - total costs, including labour) ≥ 0.
A region-specific, tested prototype that can meet the quantified objectives also needs a farm economic perspective. The existing farm structure might be an important impediment. To study the perspectives of the prototype, FSO has been developed. FSO examines the farm structure needed to describe an agronomically and ecologically optimal prototype as well as the economical aspects.

The bases for these studies are the existing results of the prototype achieved in an experimental setting. The study considers the perspectives for the near future.

The available results, however, are mostly based on an experimental *(sub-optimal)* scale, with the original *(out-dated)* costs for inputs and outputs and the original *(out-dated)* versions of the prototype. However, perspectives of integrated and ecological systems can only be estimated if subsequently:

1. inputs and outputs are technically updated considering the latest version of the prototype and possible non-system specific events or effects,
2. inputs and outputs are economically updated considering current or expected costs.

An optimal farm structure is developed considering the rates of land, labour and capital, to achieve the basic income/profit objective of net surplus ≥ 0.

Annex 4. Quantifying use and emission of pesticides

Parameters

The use of pesticides is currently often quantified as number of treat-ments, as kg active ingre-dients (PESTAS) or as a relative number expressing the ratio used dose/recommended full field dose. These parameters only quantify use and cropping tech-nique. As pesticide input in kg active ingre-dients is easy to asses and is often used in target levels for policy and label use, PESTAS-Synth and PESTAS-Cu are used as testing parameters in the VEGINECO project.

Active ingredients like mineral oil, or sulphur, with a lower environmental effect and higher concentrated in their formulations, are usually applied in a much higher dose per ha than the synthetic pesticides. Therefore, mineral compounds usually make PESTAS to get much higher values than synthetic active ingredients. On the other hand, organic pesticides, whose concentration is measured in International Units, are difficult to be assumed by PESTAS. So finally, it was established PESTAS-Synth just for synthetic active ingredients, without taking into account mineral or biologic pesticides, and PESTAS-Cu to quantify the supply of this pesticide since it can have a remarkable effect on biota and on environment.

However pesticide input gives no detailed information on how and to what extent pesticides are dispersed to the environment and what damage they do there on non target biota (Figure A4.1). If we want to now how much of a applied pesticide stays in the (a-biotic) environment independent of it is effects on biota, only the physical properties of the pesticide should be taken into account. So PAV developed a concept called Environment Exposure to Pesticides (EEP). EEP is quantified by taking into account the active ingredient physical properties (DT50, VP= Vapour pressure and Kom= bonding to organic matter) and the amount used (See intermezzo).

This concept fits into the strategy of integrated farming systems. In the development of these systems the use of this instrument follows the strategy that aims at minimising any potential effect of pesticides on biota. Therefore the exposure of the environment to pesticides (EEP) should be minimised. This should be reached by minimising the pesticide requirements of farming systems (e.g. by Integrated Crop Protection) and consequently careful selection of pesticides, taking into account the extent to which the environment gets exposed to pesticides. The approach of EEP, which enables a basic approach towards prevention, is used as instrument in VEGINECO. It is made an analysis of the highest scoring used pesticides and solutions are sought to replace them.

Combining use, emission and effects on biota one can establish the ecological risk of pesticide use. The environmental yardstick developed by CLM in the Netherlands is one of these approaches. The environmental yardstick calculates ecological risks for water life and soil life. However 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.

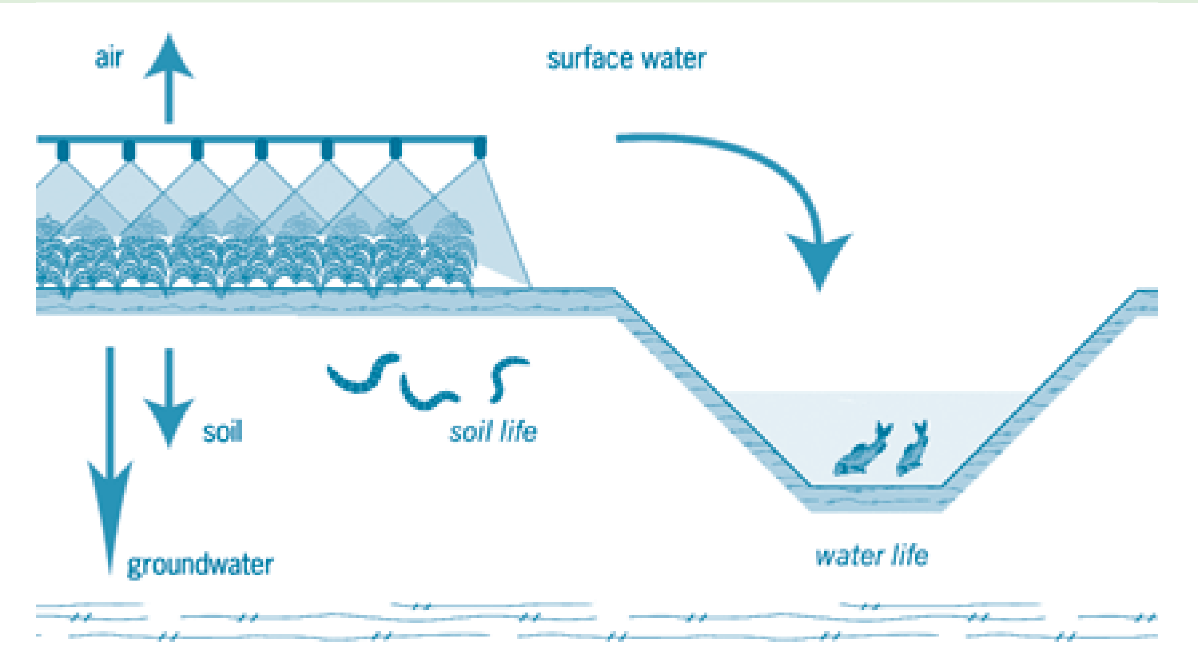


Figure A4.1 Main emission routes and main ecological effects of pesticide use

It is however not said that additional ecological information is not useful, however selection of pesticides only based on ecological effects may be misleading.

Ecological risks are not explicitly used in the testing and improving procedure of the VEGINECO systems. Main focus is on prevention of emission. Information on ecological risks is however in some taken into account as an additional criterion for selection of pesticides

So in summary, there are three levels:
1. pesticide use (PESTAS),
2. emission into the different compartments of the environment (EEP),
3. ecological risks.

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.

The EEP basic data are:
DT50 = half life time of pesticide in soil, a measure of the persistence in the soil
K_{om} = 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
$F = exp\ (-[(A \times f_{om} \times ln2 \times K_{om}) / DT50 + (B \times ln2)/ DT50 + C])$

In which:
$A = 392.5\ l\ kg^{-1}\ days^{-1}$; $B = 68.38$ days; $C = 1.092$ and $f_{om} = 0.0146$ (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 $\sum_{1-n}$ 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 $[kg\ ha^{-1}] = \sum_{1-n} (a.i.\ input_m \times emission\%_m /100)$

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* (see above)

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

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 (see above)
prec surplus = precipitation surplus $[m^3]$

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

In which:
$a.i.\ input_m$ = input of active ingredient *m* x active ingredient concentration of active ingredient *m* in a pesticide $[kg\ ha^{-1}]$
$DT50_m$ = soil half life of active ingredient *m*

EEP values per application can be summed per parameter to calculate EEP values on crop, field or farm level.

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