7 General discussion

W.Sukkel & A. García Díaz
Applied Plant Research (PPO), Lelystad, The Netherlands

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.