Course: Management of Pests, Diseases and Weeds

Sven Axel Svensson SLU Department of Landscape Management and Horticultural Technology
Birgitta Rämert SLU Department of Crop Science

Integrated pest management in cabbage production

Juliane Barten, Karin Ellgardt, Linda-Marie Rännbäck and Charlotte Olsson

2006-10-22

1 Abstract

This paper identifies key pests and diseases in cabbage production, and suggests control strategies according to IP-regulations. Important problems include the pests: small white butterfly (*Pieris rapae*), diamond back moth (*Plutella xylostella*), cabbage moth (*Mamestra brassicae*), cabbage aphid (*Brevicoryne brassicae*), cabbage root fly (*Delia radicum*), swede midge (*Contarinia nasturtii*) and the clubroot disease (*Plasmodiophora brassica)* as well as some annual weeds. The biology of them are analysed in the context of the control strategies: precautionary management strategies, chemical control, biological control and other alternative control strategies. Pesticide use and application technique are discussed in the sense of the environmental inpacts of runoff, groundwater pollution, pesticide mobilty, biodiversity and food residues. New researches of system development are presented which have made application more efficient and safe, which includes drift reduction, efficacy enhancement and precision spraying. Based on the discussion of the topics, an IP management system of pests, diseases and weeds in cabbage production is suggested.

2 Table of content

3 Introduction

3.1 Cabbage production system

This paper focuses mainly on four different cabbage crops: The white cabbage, the cauliflower, the broccoli and swede. In some sections other cabbage crops will be also mentioned.

Cabbage is a culture that occupies the field the whole season. In the general cabbage production system the crop is planted in single or double rows on flat ground. The average row distance is 60 cm and the plant distance varies from 10 to 50 cm depending on what cabbage crop is grown. The preparation of the field for cabbage production starts in autumn with ploughing which is followed in the spring with harrowing. For planting a planting machine is use while swedes and cauliflower is sawn.

Cabbage has a high nutrient demand and in order to fertilize correct soil samples are necessary. There are three important micro nutrients in cabbage production: boron, manganese and molybdenum. Deficiencies of boron and manganese occur on soil with high pH. In soils with low pH molybdenum deficiency can occur. Irrigation is done foremost with overhead irrigation. (Johansson, 1997; Adelsköld, 1991; Olsson, pers.com.)

3.2 Integrated production and conventional production

Integrated production is a strategy of growing vegetables in between conventional and organic production. Integrated production of vegetables is defined as "the economical production of high quality, giving priority to ecologically safer methods, minimizing the use and undesirable side effects of agrochemicals and to enhance the safeguards to the environment and human health" (Malavolta et al 2004).

The Integrated Production guidelines state that precautionary management strategies should first be considered. After that biological control methods should be used as far as possible and finally chemicals. When selecting a control strategy considerations must be taken on side-effects on beneficial organisms, microorganisms and pollinators. The guidelines further state that the grower should have good routines for observation strategies to detect the pests in an early stage. If prognosis or warning systems are available they should be applied and also documented. In cabbage production this foremost concerns the turnip moth (Grön Produktion AB, 2003).

In integrated production chemicals can be used against weeds, pests and diseases but reports should be made of why the treatment was done and when and how large the infestation was. Documentation should be available when pest suppression by seed treatments is used. When threshold values are defined and the limits are exceeded chemical control measures can be taken. The chemicals used should fulfill specific requirements; it should be registered and permitted by the government and fulfill requirements of GAP. A chemical that are permitted in the country may not be permitted by the IP organization. The plant protection measures are divided in a green and yellow list. The green list measures can be used without specific permissions, but reports has to been made. The yellow list selects a specific group of plant protection measures that must be available for the grower, but they have some negative side effects. The yellow listed measures are only permitted if there are "identified indications and with clearly defined restrictions" (Malavolta et al 2004). In other words it is like conventional growing but with fewer chemicals and more documentation for better traceability. Furthermore the guidelines state rules about how to store chemicals, the use of protection gear, what to do in an emergency situation, license requirements, waste and equipment handling. (Grön Produktion AB, 2003)

In both integrated production and conventional production it is legal to used herbicides and pesticides. In integrated production the weeding should first be made mechanically or by hand and if that is not effective herbicides can be used (Malavolta et al 2004).

4 Key pests and diseases in cabbage

In cabbage production several pests can cause damage over economical thresholds. In the Lepidoptera order three key pests are identified, small white butterfly (*Pieris rapae*), diamond back moth (*Plutella xylostella*) and cabbage moth (*Mamestra brassicae*). Three other Lepidoptera pests can occur in cabbage production: large butterfly (*Pieris brassicae*), turnip moths (*Agrotis* spp.) and green-veined white butterfly (*Pieris napi*), but these are not considered to be key pests in the chosen crops. However the turnip moth can cause sever damage in root crops, such as swede.

Other key pests in cabbage production are: cabbage aphid (*Brevicoryne brassicae*), cabbage root fly (*Delia radicum*) and swede midge (*Contarinia nasturtii*). Other pests that not are considered to be key pests are pollen beetle (*Meligethes aeneus*) and thrips (order *Thysanoptera*). According to Olsson (pers. com.) closeness to oil seed fields can give severe problems with pollen beetles and thrips whereas the last one causes severe quality damages. These are not mentioned in this paper.

The most severe disease in cabbage is the clubroot disease (*Plasmodiophora brassica).* Another disease which may cause trouble in storage is the black spot disease (*Alternaria brassicae)*. This disease is not considered to be a key disease and therefore not mentioned in the paper.

4.1 Small white butterfly, Pieris rapae

Larvae of the small white butterfly are a common pest on vegetable Brassicaceae crops. The eggs of *P. rapae* are singly deposited, which make the damages more spread in the field. In comparison, the eggs of *P. brassicae* are laid several (20-100) together and damage is confined to spots in field, which will often be below economical threshold (Jönsson & Jonasson, 1998; Alford, 1999).

4.1.1 Symptoms

The larvae eat small holes in the leaves. Later instars could gnaw into heads of e g white cabbage and leave large green clumps of faeces, which causes severe quality down grading (Jönsson & Jonasson, 1998).

4.1.2 Description

The forewings of the adult butterflies are white with black tips and bases, and a subcentral black spot. The hindwings are whitish with a blackish mark on the margins. The butterflies measures 4-4.5 cm in wingspan. The eggs are 1.3 mm long and yellow with longitudinal ribs. The larvae are velvet-green with fine hair growth and thin yellow lines running along the back and sides. The final instar could be 3 cm long (Jönsson & Jonasson, 1998; Alford, 1999).

4.1.3 Biology

Two generations occur per season, and the second is most detrimental to cabbage crops. The adults of the first generation occur in April, and those of the second occur from mid-summer. Their larvae feed on the cabbage leaves in late summer (Alford, 1999).
The eggs are deposited one to a few on both sides of cabbage plant leaves. The final instar pupates on the plant, to which the pupa is attached by a fine tread. The adult butterflies later emerge from the green brown pupa (Jönsson & Jonasson, 1998; Alford, 1999).

4.2 Diamond back moth, Plutella xylostella

The moth is attracted by mustard oils in all types of *Brassicaceae* plants, which are host plants. Vegetable crops are more attacked than oilseed crops. Most often infestations are below threshold, but now and then the larvae appear in large amounts during late summer (Nehlin, 1991).

4.2.1 Symptoms

After hatching the larvae enter the leaf and mine the tissue during the first instar. The larvae feed from the leaf undersides, protected in silken web, and the upper epidermis is left intact. These symptoms are called windowing. The adult larvae eats right through the leaves, riddle them and sometimes only the main veins remain (Nehlin, 1991; Alford, 1999).

4.2.2 Description

During growth, the larva changes from grey yellow with black head, to pure green with yellow head. The final instar is up to 12 mm, with elongated and fork-like anal claspers. The moth is small and inconspicuous. The wings are grey brown with a light yellow wave shaped banding pattern along the edge. In repose the wings form a characteristic pattern of three diamond-shaped marks. The wing span measures 11-16 mm (Nehlin, 1991; Alford, 1999).

4.2.3 Biology

The minute eggs (0.3-0.5 mm) are deposited in small groups on the leaf undersides and at leaf petioles during nightfall. After about 10 days the eggs hatches and the larvae emerges. If disturbed, the larva spins a thread and escapes to the ground. After 3-4 weeks, and 4 larval instars, the larva pupates in a net-like cocoon on the plant or in the soil. The adult moth emerges after 2 weeks.

Two generations occurs in Scandinavia, the first in May-June, and the second in July-September. Invasions from continental Europe, where 6 or more generations occur, during hot and dry summers could be of significant importance. The moth has been seen to over winter as pupae, egg or adult (Nehlin, 1991; Alford, 1999).

4.3 Cabbage moth, Mamestra brassicae

The larvae are common on white cabbage and cauliflower during late summer. They mainly occur on *Brassicaceae*, but have also been found in field and greenhouse on lettuce, sweet corn, sweet pepper, onion, *Fabaceae*, tomato and some ornamentals (Jönsson & Jonasson, 1998; Alford, 1999).

4.3.1 Symptoms

Young larvae gnaw on the leaf undersides, but leave the epidermis intact (windowing). The older larvae eat holes in the leaves and proceed deeply into the heads. On its way, big green to brown clumps of faeces are left behind (Jönsson & Jonasson, 1998; Alford, 1999).

Figure 1: The cabbage moth and symptoms

4.3.2 Description

The butterfly is greyish brown with black markings on the wings, and measures approximately 4 cm across. The larvae are most commonly brown, but vary from light green to dark brown, and almost lack hairs. The adult larvae will be 4 cm (Jönsson & Jonasson, 1998).

4.3.3 Biology

The cabbage moth flies in June-July. The white-greyish yellow eggs are laid in groups on the underside of leaves of cabbage plants. After about 2 weeks the larvae emerge, and

then feeds on the leaves and heads for 5 weeks. The larvae are night active and hide during the day.
Pupation within cocoons occurs in late autumn in the soil. In Scandinavia the moth only develops one generation per season (Jönsson & Jonasson, 1998; Alford, 1999).

4.4 Control strategies of Lepidoptera pests

4.4.1 Precautionary management strategies

To suppress Lepidoptera pests the crops should be grown on open and windy locations to create disadvantageous conditions. The plants should be checked regularly for eggs and larvae. Both biological and chemical control must for highest efficiency be used against young larval stages. Larvae which have penetrated heads are very difficult to control. In small fields covering with fibre cloth should be considered since this is a highly efficient method when properly timed (Nehlin, 1991; Jönsson & Jonasson, 1998).

4.4.2 Natural enemies and biological control

4.4.2.1 General approaches for all Lepidoptera

Caterpillars are reported to be attacked mainly by; predatory bugs, *Podisus* spp.; parasitoid wasps, *Cotesia* spp., *Trichogramma* spp. and Entomopathogens, especially *Bacillus thuringiensis* and Baculoviruses (Helyer et al, 2003), but parasitic fungi could also attack during moist weather (Jönsson & Jonasson, 1998).

The gregarious (colony forming) wasps *Cotesia glomerata* act as a parasitoid of caterpillars on cabbage crops. It has been quite successfully used in classical biological control programs against both large and small white butterfly. It has been shown that the wasp transmits the granulovirus (a baculovirus) of the small white butterfly, *Pieris rapae* (PrGV), leading to even higher pest control levels (Helyer et al, 2003). The wasp larvae feed within the butterfly larva, and later pupate outside the dead larval body in yellow cocoons (Jönsson & Jonasson, 1998).

Podisus spp. attack several caterpillars. Plant sap is however required to some extent in their diet, why the species prefer certain host plants. Good control has been previously been achieved of colorado beetle and in greenhouse crops (Helyer et al, 2003).

Trichogramma spp. are natural enemies and egg parasitoids of mainly many Lepidoptera species (Helyer et al, 2003).

Bacillus thuringiensis (*Bt*) is a bacteria which exists in several strains that have different effects against caterpillars and other insects. In inundative biological control, two strains could be combined to broaden the range of activity. The active ingredients of *Bt*-formulations are toxic protein crystals and viable spores. The crystals could be denatured by UV-radiation. Once intoxicated, the caterpillar ceases to feed, since the gut is paralyzed within a few hours. Death occurs after one day. Unprotected leaf-feeding young caterpillars are easiest to control. *Bt* is one of the most successful commercialized biological control agents (Helyer et al, 2003). Inundative biological control with *Bacillus* *thuringiensis* var. *kurstaki* (Turex 50 WP) works well against *Pieris rapae* and *Plutella xylostella*, but less effect is seen against *Mamestra brassicae*.

Baculoviruses infects caterpillars by ingestion of inoculated plant material. Two major types exist: nucleopolyhedroviruses (NPV) and granuloviruses (GV). A crystalline protein shell protects the virus particles, which can rest for a long time awaiting a new host. The viruses degrade the caterpillar body at different rates. Death rates are fastest in NPVs and in some GVs. Entomopathogenic viruses often have a narrow host range, and thus are environmental safe both to natural enemies and humans and show great potential as targeted inundative biological control (Helyer et al, 2003). Infectiveness of different strains of several baculoviruses was tested for Lepidoptera pests of cabbage crops by Bin Abdul Kadir et al. (1999).

4.4.2.2 Specifics for Pieris rapae

The development of the parasitoid wasp *Cotesia glomerata* has been studied in relation to the response of two of its host species: *Pieris rapae* and *P. brassicae*. This wasp lays several eggs in each host larva (so called gregarious behaviour). The parasitoid reduces the growth of the large *P. brassicae* larvae, but stimulates growth in the smaller larvae of *P. rapae*. The wasp further appeares to develop better in *P. brassicae*, where development was faster and the emerging adults was larger (Harvey, 2000). The effects of parasitism on host development vary between solitary and gregarious parasitoids. The growth of hosts parasitized by solitary species is dramatically reduced, while gregarious parasitoids enhance the growth of their host by altering the feeding behaviour. It has therefore been suggested that solitary parasitoids generally are more efficient than gregarious parasitoids as biological control agents (Harvey, 2000).

A strain of the egg parasitoid wasp *Trichogramma brassicae* was investigated as a control agent for *P. rapae* in comparison with *Bacillus thuringiensis* formulation and a pesticide. Point release of the parasitoid was found to be more efficient, with a maximum 46 % egg parasitism rate, than broadcast release. A cost-efficient pest control was achieved with *Bt* or the pesticide, but not for the parasitoid. Alternative species or strains may prove more successful (Lundgren et al., 2002).

4.4.2.3 Specifics for Plutella xylostella

Sarfraz et al. (2005) discussed several interesting prospects for biological control of the diamond back moth. Numerous parasitoid species are known to attack the diamond back moth, of which the parasitic wasps belonging to the genera *Diadegma*, *Diadromus*, *Microplitis*, *Cotesia*, and *Oomyzus* are most important (Sarfraz et al., 2005). Parasitic wasp species mentioned are e.g. *Diadegma insulare*, which probably also exploits other similar host caterpillars on cabbage crops (Helyer et al, 2003), and *Cotesia plutellae* (Rincon et al., 2006). Products derived from the fungi *Zoophthora radicans* and *Beauveria bassiana* show interesting results, as well as viruses and nematodes (Sarfraz et al., 2005). Inundative biological control with *B. thuringiensis* is very effective in controlling especially young larval instars (Nehlin, 1991).

4.4.2.4 Specifics for Mamestra brassicae

The solitary parasitoid wasp *Microplitis mediator* is a common natural enemy of the cabbage moth, of which the first to third instars are attacked. In laboratory experiments the first and second instars were most suitable hosts. Older instars are unsuitable due to aggressive behaviour and increased immune responses, but discrimination among larval instars are unlikely in field (Lauro et al., 2005).

The egg parasitoid wasp *Trichogramma dendrolimi* is a natural enemy to several Lepidoptera species. It has been used as a biological control agent against e.g. the codling moth, *Cydia pomonella*. An investigation examined the biology of the parasitoid in relation to the cabbage moth. Eggs of all ages were parasitized, but successful parasitism significantly decreased with egg age. This implies that to obtain successful control the parasitoid release should be properly timed (Takada et al., 2000).

The cabbage moth could be infected by a range of insect pathogenic fungi. Different isolates of the fungus *Beauveria bassiana* was tested against the cabbage moth with Norwegian isolates. The results showed moderate to high mortality levels, depending on isolate. The isolates in addition are assumed to have low temperature optima due to their origin, which is promising for future field uses (Klingen et al., 2002).

4.4.3 Chemical control

Lepidoptera larvae can be controlled in an early stage with a number of different pyretroids that are insecticides. Pyretroids are contact acting insecticides that have a broad and a long-lasting effect and are poisonous for almost all pollinating insects. These insecticides are very efficient specially to control larvae on the outer surface of the crops. Pyretroids are primary used in cabbage production to control Lepidoptera larvae, but aphids could also be controlled in the same time as the Lepidoptera larvaes. The pyretroids Cyperb, Decis, Fastac, Fastac 50 and Karate 2,5 can be used to control Lepidoptera larvae in all kinds of cabbage production. Two other pyretroids are used Beta- Baytroid , that is only allowed to use in chinese-, red-, green-, white cabbage and brussels sprout, and Sumi-alpha 5 FW, that is allowed in white cabbage. These insecticides have different quarantine days, the number of days between spraying and harvesting see table 1 (Jönsson et al., 2006; KEMI, 2006).

Table1: Quarantine days for different insecticides

Insecticide	**Active substance**	**Quaantine days**
Cyperb	cypermetrin	14 days
Decis	deltametrin	5 days
Fastac / Fastac 50	alfacypermetrin	21 days
Karate 2,5	lambda-cyhalotrin	14 days
Beta- Baytroid	betacyflutrin	7 days
Sumi-alpha 5 FW	esfenvalerat	7 days

(Jönsson et al., 2006; KEMI, 2006)

Other insecticides that are listed as KEMI's approved pesticides are Du-Dim 48 SC, Danadim Progress and Roxion (Sandskär, 2004, Jönsson et al., 2006; KEMI, 2006). The insecticides Danadim Progress and Roxion are only allowed in production of Cauliflower and Brussels sprouts (Jönsson et al., 2006; KEMI, 2006) and the insecticide Du-Dim 48 SC is not commonly used among the producers (Jönsson, 2006).

When applying biological agents and chemicals it is important to do so in an early developing stage of the larvae and also to apply on the underside of the leaves were the larvae is hidden. (Jönsson and Sundgren, 2005)

4.4.4 Alternative control strategies

Covering the crops with insect net or fibre cloth can give a full protection against the Lepidoptera larvae. But there are many dilemmas with this strategy. To cover the crop is very time consuming, the insect nets are expensive and the fibre cloth creates a different climate resulting in increasing temperatures which can cause quality problems (Rämert and Nehlin, 1989). When producing cabbage organically it may be the easiest to do so early or late in the season to be able to cover the crop without any quality problems caused by increase in temperature (Jönsson, pers. com.).

4.5 Cabbage aphid, Brevicoryne brassicae

The cabbage aphid is a specialist herbivore on *Brassicaceae* plants, both wild and cultivated, in most parts of the world. The most damage is seen in spring sown oilseed crops and in vegetable crops such as white cabbage, broccoli, cauliflower and swede. Infestations vary widely between growing seasons depending on the occurrence of natural enemies and climate conditions. A dry and hot microenvironment is favourable for the aphids (Jönsson & Stephansson, 2002).

4.5.1 Symptoms

Dense aphid colonies are positioned at the underside of the leaves and at the shoot tips, where the individuals feed on the plant sap (Jönsson & Stephansson, 2002).

Figure 2: Aphid colony

The first signs of aphid attack are little pale spots, but on severe outbreaks the entire leaf yellows, curls up and distorts and later shows a purplish discolouration. Outbreaks will be sparse in the beginning but rapidly spread. The growth is stunted by the aphid feeding and high infestations in young plants could lead to wilt. In larger plants a reduction in quality is seen which leads to yield losses. The aphid in addition could transmit several viruses, which are important in some growing areas (Alford, 1999; Jönsson & Stephansson, 2002).

4.5.2 Description

The cabbage aphid belongs to the family *Aphididae* and as all aphids have piercing and sucking mouth parts. The wingless cabbage aphid appears greyish due to mealy wax, but the colour beneath is greenish with small paired black patches on the abdomen. The winged females almost lack wax coverage and is dark with a yellowish abdomen which has dark spots. The siphunculi is short and barrel-shaped and the cauda short and triangular. The adult measures 1.6-2.6 cm (Alford, 1999; Jönsson & Stephansson, 2002).

4.5.3 Biology

During the summer season a rapid reproduction is ensured by means of parthenogenesis. Up to nine generations could develop in a favourable year. In northern Europe the cabbage aphid overwinters in the egg stage mainly on winter oilseed rape, cabbage crop stumps and to some extent on *Brassicaceae* weeds. Nymphs hatches and develop into wingless females, from which new parthenogenetic generations will follow. Since nymphs stay close to the mother very dense colonies will build up over time. When food resources get sparse, winged offspring will be produced and spread to other plants and other fields. During autumn winged male aphids are born which mate with wingless females. The females then deposit the eggs on cabbage plants (Jönsson & Stephansson, 2002).

4.5.4 Control strategies

4.5.4.1 Precautionary management strategies

To decrease the infestation density some precautionary actions can be made. The aphid can survive on old cabbage stalks or on *Brassicaceae*-weeds. It is therefore important to eliminate contamination sources such as old plant material from earlier cabbage cultures and also weeds that belong to the family *Brassicaceae*. Cabbage production should not be located close to fields with winter oilseed production, which also is a host plant for the aphids. Open and windy fields are recommended due to the non favourable climate for the aphid. In days with warm and dry weather repeated irrigation can decrease the infestation. It is important to be observant and make frequent field controls to notice the infestations in an early stage and treat them immediately. Field observations and field controls from midsummer is therefore important (Jönsson & Stephansson, 2002).

4.5.4.2 Natural enemies and biological control

Several natural enemies occur which can decrease the aphid population in field. Both larvae and nymphs of ladybirds (*Coccinellidae*) are ravenous aphid feeders. Other predators are larvae of hoverflies (*Syrphidae*), larvae of predatory lacewings (order *Neuroptera*) and larvae of predatory gall midges (*Cecidomyiidae*). Several parasitic wasps (order *Hymenoptera*) act as parasitoids on aphids. Many generalistic coleopterous insects (e.g. ground beetles and rove beetles) and other predatory bugs feed on aphids (Helyer et al., 2003; Pettersson, 1998). Insect parasitic fungi from the order *Entomophthorales* (in the class *Hyphomycetes*) also attack aphids and other insects under humid conditions. The fungi are very virulent and specific in their choice of host. To be effective the fungi needs a moderate high temperature, a prolonged period of humidity and a quit large insect population to ensure a rapid spread (Kuusk & Sandskär, 2004).

Diaeretiella rapae

The parasitic wasp *Diaeretiella rapae* is a narrow generalist occurring on the cabbage aphid. The wasp inserts her eggs by the ovipositor in living aphids. The larva develops and pupates inside the aphid. Parasitized aphids, mummies, turn light yellowish and have an inflated, papery appearance. Three or more generations may occur each season. Since single aphids and small colonies are preferred by the wasp, aphid control in dense colonies, such as in cabbage aphid, is rarely achieved. However, the numbers of the parasitoid have been seen to increase when diverse field margins is provided (Helyer et al, 2003).

Host range of *Diaeretiella rapae* was investigated by Antolin et al. (2006). The researchers concluded that the wasp is a serial specialist, which attacks particular hosts according to availability. Numerous aphid species could be parasitized, but only 5 to 6 are commonly attacked. It was also seen that wasp populations rearing on e.g. cabbage aphids tended to develop better on the home host compared to alternative hosts, ultimately preferring a specific host. Eventually the population would suffer reduced fitness to alternative hosts.

In the US wasps have been released in successful classical biological control programs to control the Russian wheat aphid (*Diuraphis noxia*) (Antolin *et al*., 2006).

Geiger et al. (2005) looked at the winter ecology of the aphid and the parasitoid. It appears that flower strips are not particularly attractive as winter hosts for the wasp. Winter hosts, such as crop debris favours the aphid and therefore the wasp. One approach suggested was to collect mummies from harvested cabbage crops and spread out in field margin. Parasitoids are able to emerge from fallen mummies and this would give a more effective control of aphids the next spring (Geiger et al., 2005). One release of mummies (2 mummies/m2) on cabbage plants per season enhanced the spread of the parasitoid and the parasitism, but for effective aphid control more releases per season are needed (Zhang & Hassan, 2003).

Desneux et al. (2006) investigated parasitoid species present on aphids on canola during autumn. The primary species on the cabbage aphid was *Diaeretiella rapae*. However, the parasitism rate was low and an inoculative release biological control programme during autumn could be an option.

Pandora neoaphidis

The insect parasitic fungus *Pandora neoaphidis* is known to attack cabbage aphids. In an investigation seven aphid species, among them the cabbage aphid, were infected with different isolates. Virulence tests and concentration-response analysis were conducted. The results indicated that *P. neoaphidis* could cross-infect several aphid species, which is important for conservation biological control strategies. Inoculation biological control procedures could be used in addition. The pea aphid, *Acyrthosiphon pisum*, was found to be extremely susceptible and could then act as a host in which large amounts of inoculum could be produced for later infection of other aphid species (Shah et al., 2004).

4.5.4.3 Chemical control

The cabbage aphids can be hard to control especially in crops like cauliflower and broccoli, where the aphid can hide inside the heads (Jönsson, and Stephansson, 2002). The cabbage aphid should be controlled in an early stage before dense colonies are developed, due to dense colonies are hard to suppress. Most of the aphids in this stage are covered with a waxy layer that also works like a barrier for chemical treatment.

To control the aphids in cabbage production the insecticide Pirimor G can be used. Pirimor G is a selective insecticide and therefore it is not harmful to beneficials. The active substance has a good contact acting effect and at temperatures above 15ºC it also has a good gas acting effect. When using Pirimor G it must be 14 days between that last application and the harvest (Jönsson and Sundgren, 2005 & KEMI, 2006). When applying the insecticides high pressure is recommended as well as a large liquid amount. A wetting agent is added to the spray liquid (Jönsson, and Stephansson, 2002 & Sandskär, 2004).

The different pyretroids are also efficient in control of aphids when hit, but are not allowed to be used when aphids are controlled alone. Pyretroids are not recommended due to that the pyretroids is poisonous for other insects such as beneficials (Sandskär, 2004 & Jönsson, pers. com.).

When dense colonies are observed at growth points the insecticides Danadim Progress and Roxion 40 EC can be used. These insecticides are not selective against the aphid and therefore not good for beneficial insects (Sandskär, B., 2004). The active substances (dimetoat) in Danadim Progress and Roxion 40 EC are both systemic and contact acting (Jönsson, and Stephansson, 2002). These insecticides are only allowed in production of cauliflower and brussels sprout (Jönsson et al., 2006 & KEMI, 2006).

Chemicals should only be used when it is necessary, especially non selective ones. When there are small attacks by aphids, under threshold values, the aphids can function as food sources to natural enemies that establish a population in the field. In subsequent attacks the natural enemies are already established and control of the pest is made faster. Therefore it is important to only put in a pesticide when it is necessary (Sandskär, 2004). In Sweden threshold values are lacking, but in Germany and England threshold values are applied (Jönsson, and Stephansson, 2002).

4.5.4.4 Alternative control strategies

Fibre cloth or insect net covering can also give a protection against the aphid. It is important then to eliminate potential contamination sources before the cover is put on, so the effect is not the opposite (Jönsson, and Stephansson, 2002).

4.6 Turnip root fly, Delia floralis

The turnip root fly is a minor problem in the cabbage production especially in the large production areas. The turnip root fly is primarily a problem in the northern part of Sweden and in areas with a light soil. To control this pest same control strategies as for the cabbage root fly can be applied.

4.7 Cabbage root fly, Delia radicum

In the southern and middle part of Sweden, where the largest cabbage production is situated, it is foremost the cabbage root fly, *Delia radicum*, that can cause severe damage in cabbage production.

The cabbage root fly is a pest whose larvae attack the roots of plants belonging to the family *Brassicaceae.* Among these plants are the common cultivated cabbage crops cauliflower, chinese cabbage, white cabbage and swede. The cabbage root fly can also live on different weeds belonging to this family (Jönsson and Jonasson, 1993).

4.7.1 Symptoms

The larvae feed on fibrous roots, hypocotyls and taproots, which can be totally destroyed (Jönsson and Jonasson, 1993 & Alford, 1999). The first symptom on young plants are wilting leaves and in a later stage collapsing plants. The damages on the root system hinder a normal water and nutrient uptake (Persson, 2003). Larger plants with an extensive root system are more tolerant to attack by the root fly compared to smaller plants. When the weather is favourable infested large plants can develop new roots and the damages do not need to result in large yield losses (Jönsson and Jonasson, 1993). Damaged roots are vulnerable to subsequent attack by fungal pathogens (Alford, 1999). In swede production attacks from the cabbage root fly larvae is of great importance since even small damages can cause reduction in quality that results in yield losses. In white cabbage the root fly larvae can make damage to the cabbage head and the wounds can function as infestation site for bacteria (Jönsson and Jonasson, 1993).

4.7.2 Description

The adult cabbage root fly is grey to blackish in colour (Alford, 1999), about 5 to 7 cm long and has the same appearance like the common house fly (Jönsson and Jonasson, 1993). The turnip root fly looks the same but is larger in size, approximately 6 to 8 cm long. The cabbage root fly is distinguished from the turnip root fly by the posterior papillae of the larvae that are divided in 4 and the middle pair is distinctly bifid, compared to the turnip root fly the posterior papillae is divided in 6. (Jönsson and Jonasson, 1993 & Alford 1999)

4.7.3 Biology

The cabbage root fly overwinters as pupae within a puparia. The root fly develops normally two generations per season. The first generation of adults hatches from the middle of May until beginning of June. The second generation of adults hatches 7 to 8 weeks after the first generation (Jönsson and Jonasson, 1993). The eggs are deposited in the soil close to the stem of the host plant. The egg laying period is connected to the flowering period of the common wild flower, *Anthriscus sylvestris* (Jönsson and Jonasson, 1993 & Alford 1999). The eggs hatch 3 to 7 days later, thereafter the larvae seek and attack the host plants roots immediately (Alford 1999). The larvae start to feed on small lateral roots and then continue on hypocotyls and taproots (Jönsson and Jonasson, 1993). The larvae feed during 3 to 4 weeks and then they move away from the host in to the soil and pupate (Alford 1999). A third generation of the fly is common in the southern part of Sweden but is of small practical importance (Jönsson and Jonasson, 1993).

4.7.4 Control strategies

4.7.4.1 Precautionary management strategies

To avoid a heavy infestation a good crop rotation should be applied. The fly overwinters as a pupa in the soil and therefore it is important not to grow cabbage on the same field year after year (Bligaard, 1997).

4.7.4.2 Natural enemies and biological control

The rove beetle, *Aleochara bilineata*, is as an adult a predator of e.g. the cabbage root fly larvae and eggs as well as other root fly larvae. The eggs are laid in moist soil close to plants infested with root fly larvae. The first instar is a parasitoid on fly pupa from which it later emerges as an adult (Helyer et al, 2003). The rove beetle is of most importance on the second generation of flies, but the closely related *A. bipustulata* could work as an early predator (Ahlström-Olsson, 1995). It has been mass-reared for the purpose of controlling root fly larvae on various vegetable crops (Helyer et al, 2003).

Another important enemy of the cabbage root fly is the parasitic wasp *Trybliographa rapae* (Ahlström-Olsson, 1995).

Infective juveniles of the entomopathogenic nematode *Steinernema feltiae* against young maggots have shown promising results. In greenhouse the control was effective. Summer applications were successful in field, where the surviving insects and the crop damage were reduced. In early spring the result was less convincing (Chen et al., 2003).

Conidia suspensions of the entomopathogenic fungus *Metarhizium anisopliae* was drenched onto the base of egg infested plants, which reduced the number of cabbage root fly larvae with up to 90 %. Under glasshouse conditions this treatment was comparable in efficiency to certain insecticides (Chandler & Davidson, 2005). The fungus *Entomophthora muscae* is also reported to attack the cabbage root fly (Kuusk & Sandskär, 2004).

Natural enemies of cabbage pests are attracted to the crop field by the smell of damaged *Brassicaceae* plants. In trials the natural enemies have been successfully lured by crushed seeds of *Sinapis alba* between the rows. In addition the egg laying by the cabbage root fly is to some extent disrupted, since the smell confuses the female fly (Ahlström-Olsson, 1995).

4.7.4.3 Chemical control

Seed treatments with insecticides can give a good protection in the beginning of the season and is the only chemical treatment allowed in Sweden. This strategy is very important in short cultures (Jönsson and Jonasson, 1993). In Sweden seed treatments with Birlane G and Basudin 600 EW is used, but a problem is that these two insecticides are going away from the market. Basudin 600 EW was banned the 29^{th} of September 2006 and Birlane G will be forbidden the first of July 2007. In the future the producers are forced to import seeds from abroad that are treated with chemicals which are not allowed in Sweden (Jönsson, per. com.).

Birlane Granulat (class 1L) is a specific insecticide for the cabbage root fly and is allowed in white-, red-, savoy cabbage, Brussels sprouts and swede. Birlane Granulat is spread and harrowed down in connection to sowing, planting and thinning. For application a granulate spreader is used that is connected to a sowing or planting machine. By using a specialised machine that can give site specific application the amount of insecticide could be reduced. When Birlane Granulat is applied the granulate should not come in contact with the seeds, instead the granulates should be mixed with the soil. In swede production granulates are allowed to be applied when thinning the crop, but the spread must be followed up by a row hoe so granulates are covered with soil. When using Birlane Granulat there must be 60 days between spread and harvest (Jönsson and Jonasson, 1993, Sandskär, 2004, Jönsson et al. 2006, & KEMI web-page).

4.7.4.4 Monitoring egg laying traps

The cabbage root fly egg laying can be monitored with help of egg laying traps that are placed around the neck of the cabbage plant. Ten traps per field are usually placed on representative cabbage plants close to each other. The eggs are counted each week and a prognosis can be developed (Persson, 2003). The monitoring egg laying trap can be used to determine the optimal time to put in chemical treatment or when it is time to cover the fields with a net or a fibre cloth (Bligaard, 1997 & Persson, 2003). As a monitoring method to determine the optimal time to use chemical treatment it is not useful in Sweden since the chemicals that are allowed are only used in connection to sowing or planting (Jönsson, 1997). The time for egg laying can also be used to determine the optimal time to plant. Planting should be avoided when optimal egg laying conditions occur, if the crop is not covered immediately after planting. (Bligaard, 1997 & Persson, 2003)

4.7.4.5 Cover

A good protection against the cabbage root fly can be achieved by covering the crop with a fibre cloth or an insect net. A problem is that under the cloth the climate can be unfavourably for the crop. When the temperature raise the quality of the cabbage is threatened and it is therefore important to remove the cover when the infestation risk have decreased (Hellqvist et al. 1989, Rämert and Nehlin, 1989& Persson, 2003).

4.7.4.6 Earth up the soil

When damage is observed in fields with head-cabbage crops, new root development can be triggered by earth up the soil around the cabbage stems followed with irrigation. The cabbage plant has the ability to easily develop new roots and therefore with this strategy the cabbage plants can tolerate even heavy attacks (Persson, 2003, Sandskär, 2004).

4.7.4.7 Trap cropping

Trap cropping could be a good solution to control the fly. In a report by Rousse et al. (2003), turnip (*Brassica rapa*) as a trap crop was studied in broccoli production. The trap crops function both to attract the *D. radicum* females and to attract and sustain their natural enemies, such as *Aleochara bilineta* and *A. bipustulata* that were studied. The report reveals that natural enemies were present in a higher number in the plots with the trap crop compared with the plots with only the main crop. In the plots with trap crop less broccoli plants were attacked, damages were less severe and more *D. radicum* pupae were parasitized compared with pure broccoli plots. *D. radicum* females did not lay fewer eggs on broccoli plants in plots with the trap crop compared to plots with only broccoli. The best protection and most parasitized pupae were found close to the turnips plants in the plot.

4.7.4.8 Intercropping

Morley and Finch (2003) found that in an intercropping system with clover and a cabbage host plant a clear relationship could be seen between intercropping with clover and the number of eggs laid by the cabbage root flies. More flies landed on host plants surrounded by bare soil backgrounds than on plants surrounded by clover.

Dosdall et al. (2003) saw that cabbage root fly damages and oviposition declined when weed management was delayed from the two- to the six-leaf stage of spring oilseed rape development. The root fly damage caused by weed interference was significant when weeds were removed at the two- and four-leaf stage but not at the six-leaf stage. The reduction in damage and oviposition when weeding is delayed were suggested to be connected to the *D. radium* female behaviour before egg deposition on a suitable host plant. According to Finch (2000) egg laying behaviour involves a chain of reactions. In diverse backgrounds the behaviour is interrupted by inappropriate landings on non host plants and during the spiral flight before egg deposition the fly can loose track and thereby the behaviour in interrupted.

Morley et al. (2005) reports, that once a fly landed on a non-host plant (clover), the host finding process was disrupted even though the fly was only a few centimetres away from the host plant. Flies that initially landed on a non-host plant or got lost from a host plant and moved on to a non host plant had to start the process again to be stimulate egg laying. When flies landed on the host plant the behaviour including hops and spiral flights were induced and when landed on non-hosts this behaviour was less active. The flies spent three to four times longer on the non-host compared to on the host plant, which can explain why fewer eggs were laid in intercropping systems compared to monoculture.

4.8 Swede midge, *Contarinia nasturtii*

The swede midge is a pest widely distributed in the world. The midge can attack many different plant species belonging to the family *Brassicaceae*. Most severe are the attacks on white cabbage, read cabbage, cauliflower and broccoli but also on swede and oilseed rape (Säll, 1996 & Alford, 1999).

4.8.1 Symptoms

The female midge lays the eggs deep in between the small leaves of young cabbage plants. The larva feeds on the plants and if situated close to the apical meristem the damages can be very severe resulting in failed head development, so called blind plants. Other symptoms are curling of leaves and thickened leave stems. The leaf curls develop when the growth stops at the larval feeding site, but continues on the opposite side of the leaf. Small wounds can also function as infection sites for bacteria that in combination with warm and humid weather can cause bacterial rots (Säll, 1996 & Alford, 1999).

4.8.2 Description

The adult insect is a small, delicate midge that is yellowish in colour, with long legs and antennae. The larva is pale yellowish-white in colour and can grow to be 2.5 mm long (Alford, 1999).

4.8.3 Biology

The midge overwinters as a larva in a cocoon. In the spring (from the end of May to 10th of June) when the temperature raises above 20°C and the soil humidity increases the larva pupates and shortly afterwards the adult midge hatches. Almost directly after hatching mating occurs and the female starts laying eggs in groups of 2 to 50 deep in between the small leaves of the cabbage plant. The midge does not fly large distances so the egg deposit is made on plants close to each other. The eggs hatch after approximately eight days and then the small white larvae start feeding on the plants. When the larvae are fully grown they drop to the ground and go down in the soil where they pupate in oval cocoons. Shortly after pupating the adult midge appears. Some larvae do not pupate, but instead remain as larvae in the cocoon (round in shape) in a resting stage. In this stage the larvae can rest for one or more years. The swede midge usually develops three generations per year but under good circumstances the midge can develop up to five generations (Säll, 1996 & Alford, 1999).

4.8.4 Control strategies

4.8.4.1 Precautionary management strategies

A good crop rotation is important when controlling the midge since the midge can overwinter and survive in the soil for more than one winter. Weed control is also important as *Brassicaceae* weeds can function as alternative host plants. It is important to bear in mind that the oilseed rape also can function as a host. One theory is that the first generation of swede midge is developed in oilseed rape crops and migration then occurs to cabbage crops where the second generation causes infestations. A distance of 150 – 200 m between a field with cabbage and a field with oilseed rape is enough to limit spread since the midge does not move over large distances (Säll, 1996).

4.8.4.2 Chemical control

The swede midge is a pest that is hard to control (Sandskär, 2004). Control of the swede midge is primary made by seed treatments. Today there are no efficient insecticides permitted for seed treatment in Sweden. Therefore seed treated with Gaucho is imported from abroad (Jönsson, pers com.). The insecticides Danadim Progress and Roxion 40 EC (dimetoad) can be used to control the swede midge, but are only allowed in production of cauliflower and brussels sprout (Jönsson et al. 2006; KEMI, 2006). The active substance in these insecticides has both a contact and systemic acting effect. Treatment should be made at the time when the larvae hatches from the eggs. To be able to hit the target deep in between the leaves large liquid amounts are needed so the liquid penetrates the canopy. A wetting agent is also needed, especially if the water is hard (Säll, 1996). When control of the first generation is made it is often only necessary to control the edges of the fields due to the limitation of the midge spread (Säll, 1996).

4.8.4.3 Pheromones

Hillbur et al. (2005) reports to have identified sex pheromones of the swede midge. Tests in wind tunnels have shown that a mixture of three different compounds attracted 86.8 % of the tested males to the bait. In field experiments traps baited with the sex pheromone mixture were applied to two different dispensers. The tested dispensers were rubber septa and dental cotton rolls and as a control a trap without a dispenser was used. The traps were tested 20 and 50 cm above ground. The field experiment was carried out in a field that had a low infestation of swede midge the previous year and therefore swede midges were released out in field. Approximately 30 to 50% of the released males were recaptured, which indicates that the traps are highly efficient. The majority of the recaptured males (81,9%) were caught in traps positioned 20 cm above ground and 88,4% of the recaptured males were caught in traps with the dental cotton roll as dispenser.

4.9 Clubroot disease, Plasmodiophora brassicae

The clubroot disease is distributed all over the world and considered to be the most severe disease on cruciferous crops. More than 300 different species belonging to the family *Brassicaceae* are susceptible to the disease (Wallenhammar, 1997). Among these species are several of the common grown crops for the vegetable market such as cabbage, broccoli, swede and rape. Many common weeds like charlock (*Sinapsis arvensis*), thale cress (*Arabidopsis thaliana*), shepherd’s-purse (*Capsella bursa-pastoris*) and field pennycress (*Thlapsi arvense*) are also susceptible hosts (Friberg, 2005, refers to Karling, 1968).

4.9.1 Symptoms

The first symptoms on infected plants are pale green to yellow leaves. In a later stage wilting in the middle of hot summer days is seen, which recovers during the night (Agrios, 1997 & Wallenhammar, 1997). The most characteristic symptom of the disease are swellings of the roots and hypocotyls (Wallenhammar, 1997 & Dixon, 1981). The swellings can cover the whole or a part of the root system (Agrios, 1997 & Wallenhammar, 1997). Infested roots have a limited capacity for uptake of water and nutrients due to the swellings, which often leads to nutrient deficiency symptoms (Wallenhammar, 1997 & Friberg, 2005). The disease can kill younger plants soon after infections while older plants may survive but fail to produce heads and can become stunted (Wallenhammar, 1997).

4.9.2 Biology

The clubroot disease is caused by the pathogen *Plasmodiophora brassicae* which is a primitive fungus belonging to the Plasmidiphorids, a group of obligate, intracellular plant parasites (Wallenhammar, 1999). The vegetative phase of the pathogen consists of a plasmodium, a multinucleate mass of protoplasm lacking a cell wall (Dixon, 1981; Wallenhammar, 1997). The plasmodium is only produced inside the host cells (Wallenhammar, 1997) and can give rise to zoosporangia or to resting spores which can germinate and produce zoospores (Agrios, 1997).

The life cycle of *P. brassicae* is divided into two phases. The primary phase occurs in the root hairs and a secondary phase in the cortex cells in the root. Resting spores in the soil are stimulated to germinate by plant exudates from the plant roots of the host plants. When germinating, a primary zoospore is developed that penetrates the root hairs and inside it develops into a plasmodium. The plasmodium undergoes several cleavages and develops a multinuclear plasmodium. Thereafter the plasmodial cytoplasm cleaves to form multinucleate zoosporangia that release secondary zoospores into the soil through pores dissolved in the host cell wall. Some zoospores reinfect root hairs; other zoospores fuse in pairs to produce zygotes which can cause new infections in cortical cells in the main root. The zoospores move in the soil from the root hairs to the roots epidermis and cortex cells where a secondary plasmodium is developed. When a plasmodium is developed in a cell it releases a substance which stimulates the host plant cells to abnormal enlargement and abnormal division resulting in swelling of roots. Non invaded cells can also be stimulated to abnormal growth. The plasmodium cleaves to form large numbers of resting spores which are released into the soil when the infected roots are degraded (Ingram and Tommerup, 1971, Dixon, 1981, Agrios, 1997, Wallenhammar, 1997, and 1999). The resting spores can survive in the soil for several years. Wallenhammar (1996) found that the half-life for the soils infestation potential is 3.6 years and heavy infested fields can have sources of spores up to 17 years after a host crop.

4.9.3 Factors influencing the disease outbreak

4.9.3.1 Soil moisture

The soil moisture is considered to be one of the most important factors influencing the degree of infection, development and severity of the disease (Wallenhammar, 1999). Moisture is necessary for the zoospores to move in the soil. Heavy infections are connected to poorly drained soils and soils that can keep a lot of water such as soils containing fine silt and clay (Wallenhammar, 1997 and 1999).

4.9.3.2 Soil temperature

Soil temperature is another factor. Most severe damage can be expected in fields that are sown or planted when the soil temperature is high. The optimal temperature for germination of the resting spores is +25º C but germination can occurs at +6ºC. Inside the host the optimal temperature for the pathogen development is between +18 and 24ºC but infection can occur at temperatures above +9ºC (Wallenhammar, 1999).

Hellqvist et al. (1989) reports that cover with a fibre cloth can increase the risk for severe infestations of clubroot disease. Cabbage plants and *Brassicaceae* weeds in the field were infested by the clubroot disease, but severe damage was only seen in plants produced under the cloth, which resulted in yield losses. The high temperatures under the cloth favoured the pathogen and the infestation rate was increased. The cover could also result in an earlier infestation compared to plants produced without cover.

4.9.3.3 pH in the soil

PH is also a factor influencing the disease. Clubroot disease is often associated to soils with a low pH (Dixon, 1981; Wallenhammar, 1996). Wallenhammar (1996) reports that infestations of clubroot were found on fields with pH values ranging from 5,2 to 7,5 and that the gained values corresponded with other trails reported according to Wallenhammar in literature.

4.9.3.4 Soil texture

Soil texture is another factor. According to Wallenhammar (1996) infections have been observed on all types of soil. The heaviest infections have been found on clay soils and silt soils. Soils with a low content of organic matter are found to have larger infestations than soil with a high content of organic matter (Wallenhammar, 1996). Soils that have been compressed by heavy machinery are not suitable of cabbage production since compaction leads to poor drainage (Wallenhammar, 1997).

4.9.3.5 Crop rotation

In the study by Wallenhammar (1996) there was a direct relationship between the level of infestation and the number of oilseed crops in the crop rotation. The highest level of infestation was found on the fields were the highest number of oilseed crops was grown.

4.9.4 Control strategies

There are no chemicals that can be used in Sweden to control the pathogen *Plasmodiophora brassicae*. Therefore control is focusing on elimination resting spores by avoiding host crops on infested fields. This can be avoided by taking soil samples before sowing or planting on the field. The soil sample is analysed to determine the soils content of *P. brassicae* resting spores, by a modified bioassay, which involves an indicator plant that easily gets infected when spores are present (Wallenhammar, 1997).

The disease is easily spread with soil particles containing resting spores. These soil particles can be spread with help of machinery, infected plant material, wind and water. Soil worms can also help to spread the spores. In the past the disease was also spread by animal manure when infected crops were used as fodder (Wallenhammar, 1997). Therefore it is important to avoid spread of infected soil by cleaning equipment.

4.9.4.1 Resistant cultivars

Researchers all over the word have worked during a long time with developing resistant cabbage cultivars. Developing a good resistance towards the pathogen that causes the clubroot disease is not easy since many different races of the pathogen *Plasmodiophora brassicae* exist. There have been tolerant cultivars on the market, which develop heads of saleable quality in spite of heavy infection. Tolerant cultivars are not recommended due to that the pathogen is not controlled instead it is multiplying in the field (Wallenhammar, 1997).

Säll (2006) reported in the magazine Viola that the company Syngenta Seeds has introduced a number of clubroot resistant cauliflower and white cabbage cultivars. These cultivars are assumed to be resistant against all the known races of the pathogen. The cultivars are reported to have been tested on infested soil with good results. The introduced white cabbage cultivars are: Tekila F1, that is a fresh consumed cabbage cultivar that develops in 100 days, and is also resistant against *Fusarium*; Kilaxy F1, that is a cultivar for long-term storage and develops in 120 days; Kilazol F1, is a new cultivar that is going to be tested during the growing season 2007 and develops in 130 days; Kilaton F1, that is a very hardy cultivar that develops in 140 days. The two cultivars Tekila and Kilaton are reported to have shown good results in test productions in Sweden and Denmark. In cauliflower one resistant cultivar is introduced, Clapton F1, that is a male sterile hybrid that could be produced from early summer to late autumn. This cultivar has shown good results in test productions with almost 90% of cabbage heads of saleable quality. Next year a second cauliflower cultivar, Clarify F1, is going to be introduced for field tests (Säll, 2006).

4.9.4.2 Crop rotation

How often crops belonging to the family *Brassicaceae* can be produced on a field depends on the specific field condition in form of soil texture, soil acidity and permeability. The crop rotation must be adapted to these conditions. Fields with no infection is recommended an interval between host crops of 5 to 6 years. On soils with large water content like silt soils a longer interval is recommended. Wallenhammar (1996) have found infestations on fields with long intervals between host crops as well as on fields with short intervals between host crops. It is important to remember that oilseed rape also is a suitable host.

4.9.4.3 Stimulate germination without host plants

To stimulate germination of resting spores in absence of host plants is of great interest for the control of the disease. It has been suggested that non-host plants not belonging to the family *Brassicaceae* have the ability to stimulate germination (Macfarlane, 1952). In a doctoral thesis by Friberg (2005) non-host plants effect on *P. brassicae* spore germination was studied. Three non-host plants that were expected to have a stimulating effect *Lolium perenne* (perennial ryegrass), *Allium porrum* (leek) and *Secale cereale* (winter rye), one non-host expected to have a non stimulating effect *Trifolium pratense* (red clover), as well as a host plant *Brassica rapa var. pekinensis* (Chinese cabbage) were studied. The study included a laboratory experiment, a greenhouse experiment and a field experiment. In the laboratory study root exudates of *Lolium perenne* stimulated germination of resting spores more strongly than other tested non-host plants or the host plant. In the greenhouse and field study, when the plants were grown in soil, none of the non-host plants were more effective than the other.

4.9.4.4 Liming

By adding lime the pH increases and at high or neutral pH the spores of the pathogen germinate poorly (Agrios, 1997). Liming is a widely used control method against clubroot disease. Regular liming in the crop rotation can hinder the pathogen to multiply in the soil. According to Dobson et al. (1983) the best control is gained when the lime is mixed into the soil, when small particle size of the limestone is used and when calcium nitrate is used. Wallenhammar (1999) refers to a report by Colhoun (1953) that suggests that lime may control the disease when the spore concentration in the soil is low, while in heavy contaminated fields even large applications of lime may not be efficient to control the disease. Fletcher et al. (1982) report that disease control and significant increases in yield in cabbage were obtained when large applications of calcium carbonate, sodium carbonate and gypsum were applied to field plots. The experiments indicated that not only pH but also the calcium ion concentration affects the infestation of clubroot. The pH change had the greatest effect on severity of the diseases. However the inoculums were maintained in the soil and when the calcium level and the pH value decreased the disease might be induced.

4.9.4.5 Weeds

It is important to have an efficient weed control since many of the common weeds that belong to the family *Brassicaceae* also function as hosts for the pathogen (Wallenhammar, 1997). If weed is not controlled the pathogen multiplies also in-between cabbage crops.

5 Weed control

Weeds are defined as plants that grow on places were they should not be, such as old crops from previous growing seasons or wild plants (Fogelfors 2004). Weeds compete for the same resources as the crops, such as sunlight, nutrients, space and water. The weed should be managed in order to increase crop yields. Therefore it is of importance to decrease weed infestations during the first 30 days when the plants are in a critical period. It could be advantageous if there are some weeds in the field before crop emergence, since the weeds will act as a prevention to wind erosion (Ascard 2003, Dock Gustavsson 2003). When the crops have grown bigger they can compete better with the weeds, especially cauliflower is a good competitor since the leaves prevents the sun radiation to reach the weeds (Agamalian et al 1992). If there are great amounts of weeds at the end of the season there is a higher risk of fungi attacks because the field can not dry sufficiently after rainfall since the crop and the weed hold a lot of water (Ascard 2003). The weed is not only a problem due to competition but can also function as a host for pathogens and pests. When pathogens and pests are present in weeds a faster and earlier invasion of the crop can occur. It is therefore of importance to have knowledge of how to handle the weeds by different methods and guidelines (Agamalian et al 1992).

5.1 Grouping of weeds

Weeds are divided into three groups: annuals, biennials and perennials. Annual weeds are propagated only by seeds, which grow during the season and spread their seeds. In the autumn the weed plant dies. Annual weeds survive the winter as seeds. The seed lies in the soil until it germinates when favourable conditions occur in spring. Biennial weeds are also seed propagated. Compared to annual weeds the biennials survive the winter in a vegetative stage and flowers first the second year when they also spread their seeds. Most of the biennial weeds are located in the borders of the fields. A perennial weed grows year after year and has a well developed root system. The part of the plant that grows above the ground dies in autumn but the roots are still alive and new shoots are developed in spring (Fogelfors, 2004). It is of great importance to take away the weeds before they have their flowering period, both in conventional, IP and organic production (Dock Gustavsson, 2003).

5.1.1 Weeds in cabbage production

In cabbage production foremost the annual weeds that can cause problems. In the following text the most common are presented.

5.1.1.1 Charlock, Sinapis arvensis

The charlock is present in almost the whole country but is limited in the north. It is a summer annual that is spread by seeds and the seeds have a long life cycle in the soil. The flowering period occurs from June to October (Weidow, 2000).

5.1.1.2 Common Groundsel, *Senecio vulgaris*

Common groundsel is present in whole Sweden. It is spread by seeds and grows fast. In one year the common groundsel can develop many generations. The flowering period is from March to November (Weidow, 2000). The seeds of common groundsel can not germinate if buried deeper than one cm in the soil. By harrowing and ploughing it will come deeper down in the soil and not germinate (Agamalian et al. 1992). The weed is common in soils with a lot of nutrients (Mossberg, 2003).

5.1.1.3 Field pennycress, *Thlapsi arvense*

The field pennycress is present in whole Sweden (Weidow, 2000) and is common on sandy or clay soils (Mossberg, 2003). Field pennycress is a summer- and winter annual that is spread by seeds. Flowering period is from May to October (Weidow, 2000).

5.1.1.4 Lambsquarters (Goosefoots), *Chenopodium* spp.

Lambsquarters is present in whole Sweden. It is a summer annual that is spread by seeds and has a large seed production. The flowering period is from July to September. It is of great importance to take away the flowers before seeds spread, because the seeds can survive in the soil for many years waiting for the right time to germinate (Weidow, 2000). The Lambsquarters is a common weed on fields (Mossberg, 2003).

5.1.1.5 Nightshades, *Solanum* spp.

The nightshades are present mostly in the south of Sweden. It is a summer annual that is spread by seeds. The flowering period is from May to July (Weidow, 2000). There are two species of nightshades causing trouble in cabbage production: hairy nightshade (*Solanum sarachoides*) and black nightshade (*Solanum nigrum*). Nightshades are most common when cabbage crops are cultivated directly after potatoes or tomatoes (Agamalian et al. 1992). The nightshades are common on soils with a lot of nitrogen (Mossberg 2003).

5.1.1.6 Shepherd's-purse, *Capsella bursa-pastoris*

Shepherd's-purse is also present in the whole country. It is a summer and winter annual that is spread by seeds. The flowering period is from April to October and it is of great importance to control the weed before flowering since it has a big seed production (Weidow, 2000).

5.1.1.7 Thale cress, *Arabidopsis thaliana*

The thale cress is present in the south and middle of Sweden and is a summer annual that is spread by seeds. Flowering period occurs from April to June and it is common on dry almost sandy soils (Mossberg 2003).

5.2 Herbicides

5.2.1 Application methods of herbicides

Herbicides can be applied before planting (preplant) and after planting (postplant). The most common way of spraying is by using a boom sprayer (Agamalian et al. 1992). There are two types of herbicides: contact acting and systemic acting. When using direct acting herbicides the leaves must be hit and the herbicide acts on the hitting place. Systemic herbicides are taken up by the roots or leaves and spread within the plant, which stops or disturbs the growth of the weed (Fogelfors, 2004).

5.2.2 Permitted herbicides in cabbage growing 2006

5.2.2.1 All cabbage species

Butisan S, *metzaklor 500g/l* can be used against annual weeds in direct sown cabbage. This herbicide should be sprayed direct after the sowing. When cabbage is planted, Butisan S should be sprayed 8 to 10 days after the planting (Jönsson et al. 2006). The active substance is systemic and contact acting (Fogelfors 2004).

Matrigon, *klopyralid 100g/l* can be used against thistles and camomile (Jönsson et al. 2006). The active substance is contact acting with little effect on the roots (Fogelfors, 2004).

5.2.2.2 Cauliflower and white cabbage

Focus Ultra, *cyklxidium 100g/l* can be used against all kinds of herbaceous weeds (Jönsson et al. 2006**).** The active substance is contact acting (Fogelfors, 2004).

5.3 Mechanical weeding

In organic production chemicals are not allowed and therefore the producers depend on mechanical and hand weeding. Weeds are the main problem in organic production and within the weeds the annual weeds are the biggest problem. When annual weeds are growing within the rows mechanical weeding is difficult. Therefore weeding has to be made by hand which is an expensive method. In between the rows the weeding is made by mechanical weeding (Ascard, 2003).

The mechanical weeding should be made at an early stage before the weed has grown too big. It is also important that the weeding is made often and as close to the rows as possible. The usual way of mechanical weeding is made with a fingerweeder. In single planted rows the fingers on the fingerweeder can come as close as five cm from the row, in double rows the fingers can come as close as 10 to 12 cm from the row. The first weeding can be made when the plants are visible. As soon as new weeds have developed the weeding has to be repeated. The best is if the weeding can be done once a week until the plants has grown large enough so that the rows can touch each other. It is of importance to never let the weeds take over. Direct after the mechanical weeding the hand weeding has to take place. Another common way of controlling weeds is by false sowbed. This involves preparing the soil for sowing, by harrowing in an early stage without harming the soil structure and at the same time stimulating weed germination. Just before the planting or sowing a weed control is made (Ascard, 2003).

5.4 Precautionary management strategies

There are a lot of methods to get rid of weeds. The weed management starts long before the planting of the new crop. In fact directly after the crop that was in the field before. A lot of the weed management is made by machinery or by hand, both in conventional, IP and organic. Repeated cultivation is integral to good weed management, ploughing is another. When ploughing, the soil is turned and the weeds buried in the soil and the roots of perennial weeds are cut of. To reduce both weeds and costs the best way is to choose a field that is not infested with weeds. When reducing weed infestation a lot of planning has to be made. Crop rotation is one way of planning away the weeds.

5.4.1 Choice of field

As in all production a good soil is of importance. It is important to evaluate the pH, soil structure, drainage and the manure often to get the best soil possible. The crop rotation is also of great importance. With right crop rotation the weeds can be kept down. In vegetables it is easy to get a lot of annual weeds so it is really important to try to keep the weed population down (Agamalian et al. 1992). This can be done by taking away the weeds before flowering. The seeds from an annual weed can survive in the ground for many years and wait for the right time to germinate which can cause problem for many years (Agamalian et al. 1992, Dock Gustavsson, 2003). In white cabbage, cauliflower and broccoli earth up can be a way to get rid of the weeds and also to make better growing conditions for the crop (Adelsköld, 1991; Ascard, 2003). By earth up the weeds are covered by soil, which is best done when the weeds are in the cotyledon stage. The earth up is made with special equipment and a fingerweeder can also be used to take away the weeds (Ascard, 2003).

5.4.2 Covering of the soil

By covering of the soil the weeds can be taken away. The covering makes it hard for the weeds to get the sunlight they need. There are two ways of covering the soil. In larger production it is made by organic matter. Before covering the soil with organic matter it is of importance to have a field free of weeds. If there are weeds on the field the organic matter covering can be an advantage for the weeds. The covering of the organic matter shall be 5 to 10 cm thick. In smaller productions the soil can be covered by plastic. When using plastic cover the water supply is given by drip irrigation under the plastic. The plastic covering is not only an advantage to get rid of the weeds; it provides also cleaner crops (Ascard, 2003).

6 Application Techniques

In the cabbage production nowadays normal boom sprayer like in agricultural crops are used for pesticide application. Since this machinery was not developed for the usage in vegetable row crops a lot of potential for improvement can be detected.

Some important facts should be mentioned in the beginning: Checkups for spray equipment are not mandatory but advised in Sweden whilst for example in Germany they are every second year. This provides decreasing of dangers for environment for example through leakages and the smoothly flow of application operations with efficient machinery. A law of this kind in Sweden could encourage the growers to take more intensive care of their spraying equipment. Function tests are included in the IP rules. Furthermore there are big efforts in Germany to test sprayers concerning their drift reducing ability. Sprayers which meet the requirements of a certain German guideline are registered in a list of drift reducing sprayer (Rautmann, 2003). This list provides helpful information for the grower.

Aims in pesticide application are the precise delivery of pesticides to achieve desired effect, avoid losses and use as less chemicals as possible in order to save money and protect the environment.

6.1 The Future of Application Techniques

Several institutions all over the world are intensively engaged with development and observation of development in application technology. In this chapter only the latest developments with importance for the future shall be outlined. An improvement of the application technology is fundamental for enhancing crop protection and decreasing environmental impact.

According to Smith et al. (2003) achievements over the last three years focused on application system development, drift management, efficacy enhancement and remote sensing whereas the last one is necessary for targeted spraying only on areas where pests are present. The following facts are taken out of that paper if not stated otherwise.

6.1.1 Application System Development

Within the application systems two new approaches may be of importance for the future. First there is the development of a sensor-controlled hooded sprayer for row crops that provides no continues spraying but sprays only when the sensor detects weeds. The hoods minimize spray drift concern. In an eight-row evaluation the interrupted spraying showed the same achieved control, with 63 % savings in herbicides applied, compared to continuous spraying systems. This sprayer is already marketed worldwide from the USA. The second development is a new approach to direct injection systems. The injection of a pesticide concentrate at or near the nozzles can be adapted to the ground speed. This gives spray uniformity along the row.

6.1.2 Drift Management

The combined effect of drop size distribution in the spray and environmental conditions to which the spray is exposed determines the potential for spray to drift. Therefore concerning drift management the drop size is of most importance.

There are several factors that influence the drop size and drop size distribution within the spray. Three newer approaches to acquire these characteristics worth mentioning are new nozzles, spraying system technology and modifying the physical properties of the spray mix.

Pre-orifice metering and air-induction nozzles were introduced by manufacturers. In pre-orifice metering nozzles the chemical is added at the right amount to the water shortly before it is released from the nozzle. In different evaluations it was shown, that both drift-reduction technologies produces sprays with larger volume-median-diameter and fewer drift-prone droplets than conventional nozzles, whilst the air-induction nozzles provided better drift-reduction results.

A newly developed spraying technology is also already on the market. Therein the spray is pulsed on and off by system and the times can be proportioned individually. Therefore application rate can be adjusted without changing pressure and the best pressure/nozzle combination can be chosen for the desired droplet distribution. A useful side-effect is that the pulse control also compensates speed variations. Researchers found out that the drift sensitivity can be compared with the one caused by air-induction nozzles in combination with continuous spraying.

Through modifying the physical properties of the spray mix a decreased sensibility towards drift can also be reached. Drift-control adjuvants increase volume-median-diameter and reduce proportion of small droplets. One severe disadvantage showed up in researches: A lot adjuvants were adversely affected by circulation through a pump whereas increased passes through decreased the effectiveness of adjuvants.

6.1.3 Efficacy Enhancement

A lot of other points of interests in horticulture and agriculture efficacy is influenced by several factors too. To adjust every factor in order to get the best result was and still will be of concern for growers. The grower has to take care that the known required dosage is placed on the target. By proper selection of application equipment e.g. air assistance the spray deposit and uniformity can be controlled. The usage of adjuvants and surfactants enhances the action of pesticides or modifies interactions between the droplet and target surface. Further factors the grower has to take care of are the life stage of the pest in order to provide the best effect and the environmental conditions for minimizing drift, evaporation and runoff (see chapter “Runoff”). By adjusting all these factors the efficacy will be enhanced.

6.1.4 Remote Sensing, Patch Spraying and Precision Agriculture

In common field crop production the whole field is covered with pesticides at application. Since fields are not uniform weed, pest and disease pressures within the cropped area is often patchy (Miller 2003). One can react on that with using the recent developments in relatively cheap and robust computer-based control systems. Through this system the grower has the possibility to just spray the area where weeds, pests or diseases are present. Besides the high decrease of pesticide usage other improvements provided by this system are automated record keeping and traceability and automatic steerage and guidance (Miller, 2003).

The required system components are detection, decision and application module whereas there are strong interactions between them (Miller, 2003). For the detection module two different possibilities can be applied: producing a prepared map or the real-time precision management (Smith, 2003).

Due to the fact that there are several disadvantages for real-time precision farming the map system has advanced. In short these downsides are:

- At the same time the pesticide should be applied the problem must be detected and therefore the system is strongly depending on weather conditions.
- In most cases during critical periods for control the detection of pests is difficult and the technology is not yet developed enough to make it more efficient than field monitoring done by the grower.
- All modules have to be carried at the same time and no beforehand calculation of the needed pesticide amount can be done.

Since all three modules can also be used separately an in-field location that is map-based can be applied. The most probable used method for this system is GPS (Miller, 2003) because it enters the field crop production more and more. A lot of data can be used to produce the map e.g. from harvester, scouting and remote sensing. A further technique to spot insects, weeds or diseases is to detect their favourite areas. Research will be done to predict where for example insects gather and feed and this data will be transferred as an on/off instruction map to the sprayer (Smith, 2003). Soil samples and geostatistics are of importance in this process.

The resulting data can also be used to estimate the required dosage since soil properties influence the fate of applied chemicals (see also chapter Mobility properties of active substances). If there is for example high organic matter and clay present more preemergence herbicides have to be applied because they are sorbed to the particles before interacting with the weeds.

Equipped with such maps one knows ahead how much active substance is needed. Applying patch spraying for weeds can typically save up to 40 % of herbicides (Miller, 2003). Furthermore in the first studies no yield differences between conventional and patch spraying management could be seen.

Finally the financial, environmental and traceability effects has to be mentioned. Miller (2003) described them in his paper:

The pesticide savings must be set against the capital cost of the equipment, the time and expertise required and the higher level of management input. Through adopting the whole precision farming system benefits can be used within the whole enterprise and costs can be reduced.

Concerning the environmental aspect there is first of course the decrease of applied pesticides. One side effect is that field areas with relatively low productivity can be taken out of primary production and used to deliver managed environmental benefits such as shelters for predators. Further more there is the possibility of modifying the delivery of pesticides close to field boundaries and other environmental sensitive sites if the growers is using a spraying technology that can be adapted to this.

It is a fact that growers do not like or sometimes even do paper recordings incompletely or incorrectly. This system can take care of it, when it additionally knows what chemicals in what amount it applies which it not possible yet. Therefore an electronic identifier on the packing has to be developed. Already today more traceability can be provided.

A future perspective is the steering control done through the system which can reduce the use of pesticides even further.

7 Environmental Impacts

The production of vegetables has one of the highest environmental impact among all cultivated edible crops. There are several reasons for this problem. Primarily the management system of this crop is very resource intensive. The currently practised system requires large percentages of bare soil on the fields between the rows. The effects of this will be described in the chapter “Runoff”.

The consumers have high demands concerning high quality products. Therefore the grower or farmer fights pests and diseases even more intensive then he would do in crops for feeding animals. If applied wrong this action stands in direct contrary to the residue problems that can lead to health hazards. The chapter “Food Residues” will take care of this topic.

7.1 Pollution

Speaking of environmental pollution through pest management the influences of chemicals towards surface and ground water must be mentioned first of all. As basic information the mobility properties of the active substances within the soil should be looked at, followed by information concerning runoff in cabbage production.

7.1.1 Mobility Properties of Active Substances

Pesticides can be adsorpted in the soils. The intensity is dependent on the chemical properties of the active substances, their configuration and water solubility, the concentration in the soil, kind and amount of adsorption substance, pH and soil temperature. Adsorption substances for pesticides are particularly clay minerals, humic matter and metallic oxides whereas the humic matter is the most important one. The more adsorption substances are present the more pesticides can be adsorpted. The bond strength within the adsorption varies since this reaction is a balance reaction: every change within the soil solution's consistence triggers a change on the adsorption substances. Most pesticides are adsorpted by humic matter due to the fact that it has a big surface and several different possibilities for bounding.

The adsorption of pesticides makes them unavailable for transport within soil or for example towards the groundwater. Pesticides that are soluble in water are more mobile than chemicals of low solubility. Since the soluble ones are disintegrated very quickly the grower just has to take care of the applied amount so that they can be completely decomposited by microorganisms before reaching the groundwater. Pesticides that are very mobile like Endosulfan can move up to 35 cm within one year while chemicals of low solubility like Lindan move only a few centimetres (Blume, 1992).

7.1.2 Runoff

"Runoff is a term used to describe the water from rain, snowmelt or irrigation that flows over the land surface and is not absorbed into the ground, instead flowing into streams or other surface waters or land depressions." (Anomymous1, 2006) Runoff triggers soil erosion and off-site transport of pesticides and nutrients, which could be found on or close to the surface, from horticultural fields. Since this has not only an effect on natural and social environment but on the field under cultivation as well, it should be kept as small as possible. This is especially challenging because cabbage is a row crop and therefore provides comparable wide space between the rows.

Several researches have been undertaken. Management systems using bare soil between the plants, polyethylene covering or vegetative mulch can be compared. Plastic covering around the plants is not common in cabbage production but in other row crops and it is helpful to point out the differences between the management systems.

Rice et al. undertook a study from 1997 to 1999 in the USA. Using polyethylene mulch which covers up to 75 % of the field surface the researchers measured up to 100 times higher runoff volumes in this system compared to a system in that the surface was covered with vegetative mulch. They concluded that this fact was due to the decreased infiltration capacity by polyethylene covering. At the same time the runoff increased the soil erosion and contamination of the water with pesticides increased as well. Due to this direct correlation one can concentrate on reducing runoff in order to protect organic matter and the applied pesticides.

Polyethylene coverage hinders infiltration of chemicals into the soil. Hence the processes mentioned in the chapter above cannot take place and offsite transport of chemicals is more likely while no different sensitivity between the distinct active substances could be found.

An older research mentioned in this study showed that the rainfall interacts only with chemicals on top centimetre of soil and can extract them there. Thus the more the chemicals infiltrate into the soil before rain event the less the availability and therefore quantity of chemicals in runoff. This gives a very important hint for the timing of pesticide application.

The study figures that polyethylene management has greater adverse effect on surrounding environment than hairy vetch mulch management which itself is more suitable for decreasing runoff than bare soil because the organic matter on the soil surface dissipates the energy of rain drops and thereby reduces the velocity and amount of surface runoff, the displaced soil is reduced and more suspended sediments are allowed to settle out of the runoff (Rice, 2001). Additionally the usage of vegetative rows between the crop rows or vegetative strips along the edge of the field is advised.

7.1.3 Groundwater Pollution

Direct groundwater pollution, which means no pollution through surface water, is depending on several factors: the mobility of the chemical (described in chapter "Mobility properties of active substances"), the properties of the soil, the longevity of the chemicals and the number of times the soil is rinsed thoroughly (Blume, 1992).

The soils present in Mecklenburg-Western Pomerania (Germany) for example are during winter rinsed four times thoroughly within the first meter (Krieger, 2006). This is of course influenced by the soil and the rainfall. Since the average rainfall over the year is slightly higher in southern Sweden (Anoymous2, 2006) and the soil type is less sandy it can be concluded that this figure is applicable for the Swedish environment as well.

In order for chemicals to be washed out during this process it is important to make them, if they are already present in the soil, unavailable for transport. In the chapter "Mobility properties of active substances" it was explained that factors like organic matter or clay content decrease the mobility of chemicals. Therefore actions for increase of organic matter can be suggested.

The first step should of course be to cut down the use of pesticides as far as possible and the usage of chemicals that are fast disintegrated. However, since cabbage in the currently used production system is a crop that requires a big amount of bare soil one could not avoid chemicals reaching the soil and not the plants. Therefore the usage of mulch and new application technology in future can be suggested.

Two other ways on which groundwater pollution is possible are through runoff or evaporation whereas a certain percentage of pesticides reach the groundwater after being transported by surface water. When using normal boom sprayers 10 to 20 % of the pesticide amount will evaporate (Blume, 1992). This can be decreased by the usage of drift reducing techniques and the right application conditions such as wind speed under 5 m/sec (Büchi and Bigler, 2002).

7.2 Biodiversity

The usage of chemical plant protection can definitely have a negative impact on biodiversity. Thus not only within the area of application itself but also in ecosystems situated farer away. This effect can be triggered through runoff which was described above.

Jha and Mishra (2005) stated that pesticide residues accumulate within top 15 cm of the soil. Since this is also the region of the highest soil microorganism activity influences of pesticides must be looked for closely. The chemicals can be toxic for non-targeted organisms when applied in a certain dose.

It is the declared aim of the Swedish government to decrease the toxicity of pesticides and their usage for the environment. Therefore KemI (Kemikalieinspektionen) set strict rules for approval of pesticides. This is one step in order to ban chemicals that are lethal for a wide range of organisms even in a very small dosage (e.g. DDT). Concerning the environmental issues very target-specific pesticide, especially insecticides, should be the only one approved afterwards. The only problem is represented by herbicides wherein the toxicity of the selective acting chemicals is up to 16 times higher and the half-life is doubled compared to broad acting glyphosat herbicides (Menrad et al. 2003).

The next unavoidable step is to cut down the amount of applied pesticides by growers and farmers. Through this action an accumulation of chemicals in the soil and therefore more intensive impact can be avoided. Additionally it is of course important for decreasing the probability of runoff events as stated above and food residues that will be discussed further down.

Since sustainable horticultural and agricultural practice is of importance for everyone, biodiversity as one part of the system is important to preserve. While there are not many studies done it seems to be secure that an intact soil life has a positive influence towards the management of pests and diseases. The most obvious example are the microorganisms that produce nitrogen out of organic matter. Thus it can be stated that not only the pests and diseases can be influenced by microorganisms but the fertility of the soil under cultivation as well.

7.3 Food Residues

Residues in cabbage can originate from different sources but in this paper only residues caused through pesticides shall be taken into consideration. Food residues are representing the social environmental part of cabbage production.

According to guiding rule 91/414/EWG plant protection chemicals can only be approved when they cause no danger for consumer, appliers and environment. Consumer risk assessment is a crucial element in the approval, registration or licensing of pesticide uses on edible crops. The risk assessment compares the dietary intake of the pesticide residue by the consumer with a measure of levels that are acceptable. Newer risk assessments do not only focus on chronic intake as it was done until now, but they also take single, but higher doses in a shorter time into consideration which made the assessment more complex and realistic. (Hamilton, 2004) The maximum dosage of pesticides the grower is allowed to apply is derived out of these estimations. Therefore through the correct application of pesticides residues in food can be avoided.

Nevertheless the EU takes samples of vegetables, fruits and cereals in every country to ensure food security. Over the years a constant number of samples with measurable residues were discovered. In 2001 this was the case with 41 % of the samples, but only 3,9 % of the samples contained residues over the maximum residue level. Overcoming this level does not necessarily mean danger for health for consumers since it represents no toxicological threshold. Compared to the past the number of samples with residues of several pesticides is increasing. (Anonymous, 2003) Presumed that there were no failures made during production this could be seen as a hint to unknown interactions of the pesticides within the plant. Further more the most common found pesticides were fungi- and insecticides.

Within the EU food residues are of no problems as long as the production is done properly.

8 Discussion

The Integrated Pest Management guidelines state that precaution management strategies should first be considered. After that biological control methods should be used as far as possible and at last chemicals. When choosing a control strategy consideration must be taken on side-effects on beneficial organisms, microorganisms and pollinators.

8.1 Precautionary management strategies

The first thing to consider when planning a control strategy is the precautionary management techniques. In following section different precautionary strategies will be discussed.

8.1.1 Crop rotation

Crop rotation is very important precautionary tool in all kinds of production systems. In cabbage production it is most important to control the clubroot disease that should have a long interval (5 to 6 years) between the host crops even when the pathogen is not present. When the infestation is present cabbage production is not possible for a very long time (approximately 17 years). Crop rotation is also important to control pests like swede midge and cabbage root fly that are over wintering as a pupae in the soil. Some of the Lepidoptera larvae are also able to pupate in soil but are not considered as soil transmitted pests. Monoculture year after year is not recommended due to the increase of pest populations and diseases.

Weed management is also favoured by crop rotation by decreasing weed pressure. While growing different cultures different management strategies for weed controls are applied. This leads to different pressure of weed species depending on the culture in the year before.

8.1.2 Avoid provision of winter hosts

Plant debris can harbour pests and diseases over winter for example the Lepidoptera larvae, the cabbage aphid and clubroot spores. Closeness to winter oil seed crops could favour especially the cabbage aphid, which would overwinter there. By providing host plants for harbouring the pests over winter early infestations in cabbage next spring can be induced. Removal of plant debris is often managed by ploughing which will bury infected plant material that is degraded in the soil.

8.1.3 Growing conditions

By providing the crop with good growing conditions like nutrients and water the plants will be vigorous thus withstanding pest and disease invasions and weed competition.

By creating unfavourable conditions for the pests and diseases the pest population or the infestation level can be suppressed. Aphid attacks could be managed by regular irrigations with cold water since aphids is not favoured by low temperature and moisture. By altering the acidity and calcium ion concentration of the soil by liming the clubroot diseases is reported to be suppressed, when the infestation rate is low. A pH increase to a neutral or high pH is unfavourable for spore germination, but when the pH level decreases the disease can be induced again. High pH can also lead to deficiency of boron and manganese.

The choice of field is very important. It is strongly recommended to produce cabbage on soil with no infestation with clubroot. The infestation with clubroot is heavier in soils with higher water content since the zoospores are dependent on high moisture. Therefore it is important to have a sufficient drainage especially in silt and clay soils and to avoid soil compaction.

An increase of organic matter could give a better soil structure as well as an increase in the soil fertility and disease suppression. Soils with a higher content of organic matter are found to have lower infestations of clubroot compared to soils with low content.

8.1.4 Resistant cultivars

The best way to protect cabbage is by using resistant cultivars in combination with other precautionary methods. Today there exist resistant cultivars for white cabbage and cauliflower which are resistant towards most races of the clubroot pathogens. One has to be aware of the possibility that the resistance could be overcome by new races of *Plasmodiophora brassicae* and therefore heavy infested fields should not be used.

8.1.5 Weeding

Controlling the weeds within the production is of importance because they compete and interfere with the main crop. The interference can result in yield losses. Weeds are also important to be controlled because they can function as hosts especially weeds belonging to the family *Brassicaceae*. They can function as “green bridges” in between seasons and also between cabbage cultures in crop rotation. A dilemma is that unwanted plants from the brassicaceae family have to be targeted with herbicide that at the same time fights cabbage since they belong to the same family. To be able to apply this herbicide one should time the application before the cabbage is emerged or planted or target spraying technologies must be used. Another way of controlling weeds is to use the technique “false sow bed” in combination with either herbicide or mechanical weeding.

Weeds can also have a positive effect by enhancing natural enemies that can use the weeds as hosts for overwintering and multiplying. This effect can be used through delaying the weeding which also confuses the cabbage root fly and it probably causes increased biodiversity over the season on the field.

8.2 Natural enemies

If natural enemies are present in a specific number they can suppress the pest populations and thereby reduce the need of controlling the pest in another way. The strategy to increase the population of natural enemies is defined as conservational biological control. This strategy includes reducing the amount of pesticides especially the broad acting insecticides that have severe impact on all kinds of insects. The easiest way to enhance beneficials is to provide shelter in form of pesticide free field edges, flower strips and intercrops. Structurally complex agricultural landscapes containing woody habitats and pasture areas favours natural enemies, which leads to an increases pest control (Bianchi et al., 2005).

8.3 Biological control

A lot of research is going on about biological control all over the world for different crops. In cabbage several of the important natural enemies have been tested for efficacy in field trials. Many are not efficient enough to be economically justified. If different biological control agents are used in cooperation a better efficiency could be achieved. Up to date, inundative biological control with *Bt* appears superior to any other biological control treatment of caterpillars in cabbage crops, except for *Mamestra brassicae*. Baculoviruses also have the potential to become increasingly important in controlling them. Natural enemies in conservation biological control should however not be overlooked since they could make significant contributions.
Bt is commercialized as Turex 50 WP, which is the only biological control agent registered for use in cabbage in Sweden. The climate restricts the use of potential efficient control agents, e.g. fungi against the cabbage aphid. The ongoing research can eventually result in new products being released to the market.

8.4 Alternative control strategies

In this paper "alternative control strategies" will be referred to as strategies that can not be classified within the other groups of the triangle like precautionary management strategies, natural enemies, biological control and chemical control. These are strategies that are used in the growing crop.

8.4.1 Net or cloth cover

By using the cover a fully protection against pests (Lepidoptera larvae, aphids, root fly and Swede midge) can be gained, assumed that the pests are not trapped inside the cover. But the cover has many disadvantages. It is foremost time consuming and expensive and manageable only in small fields. The cover could be a good method to protect the crop from frost through better microclimate but this temperature increase later in the season can cause negative quality damages that can result in yield losses. There are also studies which have shown that clubroot disease can be enhanced due to the increased soil temperature of this management system. Another disadvantage is also that weeds favour the microclimate underneath the cloth, which maybe results in more intense weed density.

8.4.2 Monitoring

Through using monitoring methods the chemicals can be applied when threshold limit is overcome and as a result pesticides use is reduced. Monitoring can be made by observing the field or using monitoring traps. In recent studies sex pheromones where identified that could trap males of swede midge. This monitoring trap is not available on the market yet. One monitoring method that is already in use is egg laying trap for the cabbage root fly. This trap is useful to determining the right time for applying chemicals, however there are no chemicals allowed that grower can apply in this stage. But the monitoring can be applied to determine the right time to start using covers.

8.4.3 Weeding strategies

One way of controlling weeds is by covering the soil with plastic mulch or organic mulch. Germinated weeds will die because of the lack of sunlight. By covering the plants become more clean which leads to good quality. Furthermore the crop dries up faster after rain or irrigation events which maybe reduce fungi spread. Plastic mulch is very time and labour intensive and increases runoff while organic mulch is cheap and easier to apply on big fields.

Another management strategy that could be used to control weeds is earth up soil. This strategy involves that the weeds are buried by soil. It is also a good method to avoid damage when the root fly has attacked. In organic production this method is a common way of controlling weeds and it could also be used in integrated production since it is an easy method to control weeds in the first stages of crop development.
There are several methods that can be used to apply mechanical weeding. These methods are established amongst organic growers but they are time consuming compared to spraying and have to be applied very carefully. Hand weeding strategies are very expensive while effective but not the best strategy for integrated production, because it should be economically reasonable.

8.5 Chemical control strategies

On account of several reasons, that where stated in this paper, the grower should use as less pesticides as possible. Additionally hindering developments are taking place on the pesticide market. A lot of chemicals are banned or withdrawn by manufacturers.

Under the current circumstances it is difficult to control clubroot disease and swede midge due to a lack of chemicals in Sweden. To control the midge imported treated seeds are used in practice. At early attacks there are two insecticides that could be applied but they are only allowed in cauliflower and brussels sprouts. Both have a non-selective effect and therefore are harmful also for beneficials. Another group of non-selective insecticides commonly used for controlling e.g. Lepidoptera are pyretroids. These are also very efficient against the cabbage aphids but not allowed when only aphids should be controlled. The only selective acting insecticide that is allowed in cabbage production is Pirimor G which is very efficient against aphids.

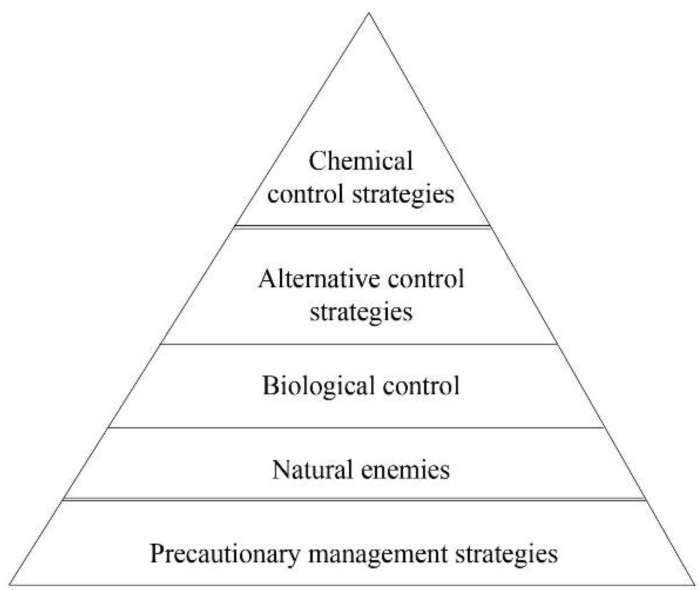
In the near future all the chemicals that are useful for controlling the cabbage root fly will be banned. Since chemicals are considered to be the easiest way by farmers they are then forced to import treated seed with chemicals that are not allowed in Sweden.

If there are selective acting chemicals available the grower should use these first. However when using herbicides one should be aware that the selective acting ones have higher toxicity and the half-life is doubled. Therefore the impact on biodiversity could be more severe. In cabbage production three herbicides are permitted, of which Matrigon is highly selective. Brassicaceae weeds must be controlled by other methods in growing cabbage crops since herbicides selective against them will kill the crop as well.

8.6 Conclusion

In order to be able to give suggestions a triangle (see figure) was developed for this paper. The discussion was already geared to the order given in the triangle.

The precautionary management strategies should be the first strategy to take in consideration, thereafter strategies such as natural enemies, biological control and alternative control should by applied. These three methods are coequal. Last chemical control should be applied.



When handling plant protection problems the grower should apply methods first that can be found close to the basement of the triangle. These are supposed to be most cost efficient in connection with the lowest environmental impact and highest possibility to gain sustainable horticulture.

Within this paper it is not possible to suggest “the best” plant protection management system in cabbage production since this is strongly dependent on the given natural and farm resources. These are individual for every grower and have to be taken into consideration when planning plant protection for cabbage. In the chapter “Discussion” this paper tried give an overview over the possible methods. How they can be applied and combined will be decided by the grower.

Furthermore in order to enhance the plant protection system according to the IP guidelines growers should try to use as modern techniques as possible. This advice is not only narrowed down to plant protection but refers to the whole production system. Another fact that should not be overlooked is that in general growers do not have time to make as many observations in the field as necessary. To solve this problem is a challenge especially since monitoring is the foundation of every plant protection method. Until today there is nothing that can substitute the field observations done by growers.

References

Adelsköld, N (1991), *Odla köksväxter på friland.* LTs förlag, Stockholm. p. 157-158, 160-161, 173-174, 167-169

Agamalian, H.S. et al (1992), *Integrated pest management for cole crops and lettuce.* Statewide pestmanagement project division of agriculture and natural resources. Publication 3307. University of California p. 95-109

Agrios, G.N. (1997), *Plant pathology*. 4th edition. Academic press, London, p. 263-266

Ahlström-Olsson, M. (1995), Kålflugans naturliga fiender, *Fakta Trädgård (1995:9)*, Sveriges Lantbruksuniversitet, Uppsala.

Alford, D.V. (1999), *A textbook of Agricultural Entomology,* Blackwell Science Ltd, Cambridge, 314 pp.

Anonymous (2003), *Kommissionsbericht:* Situation bei Pestizidrückständen in Lebensmitteln in der EU weitgehend unverändert, Brüssel

Anonymous 1 (2006), www.water-technology.net/glossary/runoff.html, 2006-10-17

Anonymous 2 (2006), www.nationsencyclopedia.com/Europe/Sweden-CLIMATE.html, 2006-10-21

Antolin, M.F., Bjorksten, T.A., Vaughn, T.T. (2006), Host-related fitness trade-offs in a presumed generalist parasitoid, *Diaeretiella rapae* (Hymenoptera: Aphidiidae), *Ecological Entomology*, 31: 242-254.

Ascard, J. (2003), Ogräsreglering i ekologisk grönsaksodling, *Jordbruksinformation,* no 21 2003: p 6-12, 17-20

Bianchi, F.J.J.A., van Wingerden, W.K.R.E., Griffioen, A.J., van der Veen, M., van der Straten, M.J.J., Wegman, R.M.A., Meeuwsen, H.A.M. (2005), Landscape factors affecting the control of *Mamestra brassicae* by natural enemies in Brussels sprout, *Agriculture, Ecosystems and Environment*, 107: 145-150.

Bin Abdul Kadir, H., Payne, C.C., Crook, N.E., Winstanley, D. (1999), Characterization and cross-transmission of baculoviruses infectious to the Diamondback moth, *Plutella xylostella*, and some other lepidopteran pests of brassica crops, *Biocontrol Science and Technology*, 9 (2): 227-238.

Bligaard, J. (1997), Kålfluer –biologi, forebyggelse og bekaæmpelse, *Grøn viden Havebrug*, no. 110

Blume, H.-P. (1992), *Handbuch des Bodenschutzes* – Bodenökologie und –belastung / Vorbeugende und abwehrende Schutzmaßnahmen, ecomed, Landsberg/Lech

Büchi, R. and Bigler, F. (2002), Abdrift gefährdet Artenvielfalt, *UFA-Revue*, vol. 4: p. 44-45

Chandler, D; Davidson, G (2005), Evaluation of entomopathogenic fungus Metarhizium anisopliae against soil-dwelling stages of cabbage maggot (Diptera : Anthomyiidae) in glasshouse and field experiments and effect of fungicides on fungal activity, *Journal of economic entomology*, 98 (6): 1856-1862.

Chen, SL; Han, XY; Moens, M (2003), Biological control of Delia radicum (Diptera : Anthomyiidae) with entomopathogenic nematodes, *Applied entomology and zoology*, 38 (4): 441-448.

Colhoun, J. (1953), A study of the epidemiology of Clubroot disease of Brassicae. *Annals of Applied Biology,* Vol. 40: 262-283

Desneux, N., Rabasse, J.-M., Ballanger, Y., Kaiser, L. (2006), Parasitism of canola aphids in France in autumn, *J. Pest Sci*., 79: 95-102.

Dixon, G.R. (1981), *Vegetable Crop Diseases*. Macmillan Publishers Ltd, London, p. 137-142

Dobson, R.L., Gabrielson, R.L., Baker, A.S. and Bennett, L. (1983), Effects of Lime Praticale Size and Distribution and Fertilizer Formulation on Clubroot disease Caused by *Plasmodiophora brassicae***,** *Plant Disease***,** vol. 67: p. 50-52

Dock Gustavsson, A-M. (2003), Ogräsarternas biologiska egenskaper, *Jordbruksinformation,* no 21 2003: p 2-5

Finch, S and Collier, R.H. (2000) Host plant selection by insects – a theory based on 'appropriate / inappropriate landings' by pest insects of cruciferous plants, *Entomologia Experimentalis et Applicata*, vol. 96: p. 91-102

Fletcher, JT., Hiems, MJ., Archer, FC. and Brown, A. (1982), Effects of adding calcium and sodium salts to field soils on the incidence of Clubroot, *Annals of Applied Biology,* Vol. 100: p. 245-251

Fogelfors, H. (2004), Bekämpning av ogräs i jordbruk och trädgård, *I:* **Arvidsson, B., Ascard, J., Barklund, P., Bång, U., Eidmann, H.H., Fogelfors, H., Larsson, H., Nilsson, E., Sandskär, B., Svensson, S.-E., Tornéus, C., Wiik, L. and Visavi AB,** *Bekämpning i praktiken –jordbruk, trädgård och skog*, Natur och kultur fakta, WS Bookwell, Finland, p. 7-14.

Friberg, H. (2005), Persistence of *Plasmodiophora brassicae*, Influence of non-host plants, soil fauna and organic material, *Acta Universitatis Agriculturae sueciae, Agraria* vol. 115: 26 pp

Geiger, F., Bianchi, F.J.J.A. and Wäckers, F.L. (2005), Winter ecology of the cabbage aphid *Brevicoryne brassicae* (L.) (Homo., Aphididae) and its parasitoid *Diaeretiella rapae* (McIntosh) (Hym., Braconidae: Aphidiidae), *J. Appl. Entomol*., 129: (9/10): 563-566.

Grön Produktion AB (2003), *Regler för Integrerad Produktion; frukt, bär, grönsaker och potatis,* Grön Produktion i Sverige AB, Stockholm, pp. 17

Hamilton, D., Ambrus, A., Dieterle, R., Felsot, A., Harris, C. Petersen, B., Racke, K., Wong, S., Gonzalez, R., Tanaka, K. Earl, M., Roberts, G. and Bhula R. (2004), Pesticide residues in food – acute dietary exposure, *Pest Management Science*, vol. 60: p. 311-339

Harvey, J.A. (2000), Dynamic effects of parasitism by an endoparasitoid wasp on the development of two host species: implications for host quality and parasitoid fitness, *Ecological Entomology*, 25: 267-278.

Hellqvist, H., Hellqvist, S. and Rämert, B. (1989), Undersökning rörande blinda plantor I blomkål, *Växtskyddsnotiser*, vol. 53 no.3: p. 64-75

Helyer, N., Brown, K. and Cattlin, N.D. (2003), *A colour handbook of biological control in plant protection*, Manson Publishing, London, 126 pp.

Hillbur, Y., Celander, M., Baur, R., Rauscher, S., Haftmann, J., Franke, S. and Francke, W. (2005) Identification of sex pheromones of the Swede midge, *Contarinia nasturii*, *Journal of Chemical Ecology*, vol. 31, no. 8: p. 1807-1828

Ingram, D.S. and Tommerup, I.C. (1972), The life history of *Plasmodiophora brassicae* Woron, *Proceedings of the Royal Society of London. Series B, Biological Sciences* vol. 180: p. 103-112

Jha, M. N. and. Mishra, S. K (2005), Decrease in Microbial Biomass Due to Pesticide Application/Residues in Soils Under Different Cropping Systems, *Bulletin of Environmental Contamination and Toxicology*, vol. 75: p. 316-323

Johansson, H. (1997), *Vitkålsodling* (P95/97 Nr. 35), Examensarbete i Lantmästerprogrammet, Sveriges Lantbruks Universitet, Alnarp, pp. 32

Jönsson, B. and Jonasson, T. (1993), Kålflugor, *Faktablad om växtskydd: Trädgård*, (22T), Sveriges Lantbruksuniversitet, Uppsala

Jönsson, B. (1997), Växtskydd I integrarad production av svenska frilandsgrönsaker, *Växtskyddsnotiser*, vol. 61 no. 2: p. 35-40

Jönsson, B., Jonasson, T. (1998), Larver på kålväxter, *Faktablad om växtskydd: Trädgård (106T)*, Sveriges Lantbruksuniversitet, Uppsala.

Jönsson, B., Stephansson, D. (2002), Kålbladlus, *Faktablad om växtskydd: Trädgård (111T)*, Sveriges Lantbruksuniversitet, Uppsala.

Jönsson, B., Persson, G. and Sundgren, A. (2006), Godkända bekämpningsmedel I frilandsgrönsaker 2006, Jordbruksverket, p 13-19

Jönsson, B. (2006), personal communication, 2006-10-17

Karling, JS (1968), *The Plasmodiophorales*, 2nd ed. New York and London, Hafner Publishing Company

Kemikalieinspektionen, (2006), Kemikaliska och biologiska preparat i kål, www.kemi.se, cited 2006-09-20

Klingen, I., Meadow, R., Aandal, T. (2002), Mortality of *Delia floralis*, *Galleria mellonella* and *Mamestra brassicae* treated with insect pathogenic hyphomycetous fungi, *Journal of Applied Entomology*, 126: 231-237.

Krieger, A.-E. (2006), lecture: *Ökologischer Landbau*, University of Applied Sciences Neubrandenburg, 2006-10-13

Kuusk, A.-K., Sandskär, B. (2004), Biologisk bekämpning av insekter med insektspatogena svampar, *Faktablad om växtskydd: Trädgård (152T)*, Sveriges Lantbruksuniversitet, Uppsala.

Lauro, N., Kuhlmann, U., Mason, P.G., Holliday, N.J. (2005), Interaction of a solitary larval endoparasitoid, *Microplitis mediator*, with its host, *Mamestra brassicae*: host acceptance and host suitability, *Journal of Applied Entomology*, 129 (9/10): 567-573.

Lundgren, J.G., Heimpel, G.E., Bomgren, S.A. (2002), Comparison of *Trichogramma brassicae* (Hymenoptera: Trichogrammatidae) augmentation with organic and synthetic pesticides for control of cruciferous Lepidoptera, *Environmental Entomology*, 31 (6): p. 1231-1239.

Macfarlane, I. (1952), Factors affecting the survival of Plasmodiophora brassicae Woron in the soil and its assessment by a host test. *Annals of Applied Biology*, Vol. 39: p 239-256

Malavolta, C., Boller E.F., Wijnands F.G. (2004), Guidelines for Integrated Production of Field grown Vegetables. *IOBC / WPRS Bulletin*, vol. 28, no.5: p. 3-9

Menrad, K., Gaisser, S., Hüsing, B., Menrad, M. (2003), *Gentechnik in der Landwirtschaft, Pflanzenzucht und Lebensproduktion*, Physica-Verlag, Heidelberg

Miller, P. C. H. (2003), Patch spraying: future role of electronics in limiting pesticide use, *Pest Management Science*, vol. 59: p. 566-574

Morley, K, Finch, S. and Collier, R.H. (2005), Companion planting – behavior of the cabbage root fly on host plants and non-host plants, *Entomologia Experimentalis et Applicata*, vol. 17: p. 15-25

Mossberg, B. and Stenberg, L. (2003). *Den nya floran*. Wahlström & Widstrand Stockholm

Nehlin, G. (1991), Kålmal, *Faktablad om växtskydd: Trädgård (94T)*, Sveriges Lantbruksuniversitet, Uppsala.

Olsson, J. (2006), cabbage producer, telephone interview, tel. no.: 0703315238, Sofiedal, 2006-10-19

Persson, G. (2003), Prognos- och varningssystem för några skadegörare I ekologisk förnsaksodling, *Växtskydd I ekologisk grönsaksodling*, Ekologisk *odling av grönsaker på friland*, Jordbruksverket, P7:20, p. 7-11

Pettersson, M.-L. (1998), Bladlöss, *Faktablad om växtskydd: Trädgård (59T)*, Sveriges Lantbruksuniversitet, Uppsala.

Pfrommer, W., Mendgen, K. (1992), Biological control of *Brevicoryne brassicae* with the parasitic fungus *Verticillium lecanii* in the laboratory and in the field, *Zeitschrift für pflanzenkrankheiten und pflanzenschutz (Journal of plant diseases and protection)*, 99 (2): 209-217. **(Abstract)**

Rautmann, D. (2003), Drift Reducing Sprayers - Testing and Listing in Germany, *2003 ASAE Annual International Meeting*, paper number: 031095

Rice, P. J., McConnell, L. L., Heighton, L. P, Sadeghi, A. M., Isensee, A. R., Teasdale, J. R, Abdul-Baki, A. A., Harman-Fetcho, J. A. and Hapeman, C. J. (2001), Runoff Loss of Pesticides and Soil: A Comparison between Vegetative Mulch and Plastic Mulch in Vegetable Production Systems, *J. Environ. Qual.*, vol. 30: p. 1808-1821

Rincon, C., Bordat, D., Lohr, B., Dupas, S. (2006), Reproductive isolation and differentiation between five populations of *Cotesia plutellae* (Hymenoptera : Braconidae), parasitold of *Plutella xylostella* (Lepidoptera : Plutellidae), *Biological Control*, 36 (2): 171-182.

Rousse, P., Fournet, S., Porteneuve, C. and Brunel, E. (2003), Trap cropping to control Delia radicum population in cruciferous crops: first results and future applications, *Entomologia Experimentalis et Applicata*, vol. 109: p. 133-138

Rämert, B. and Nehlin, G. (1989), Alternativa bekämpningsmetoder I småskalig odling, försöksresultat 1986-1988, *Växtskyddsnotiser*, supplement 2, Mars 1989

Sandskär, B. (2004), Bekämpning av skadedjur på jordbruks- och trädgårdsväxter, *I:* **Arvidsson, B., Ascard, J., Barklund, P., Bång, U., Eidmann, H.H., Fogelfors, H., Larsson, H., Nilsson, E., Sandskär, B., Svensson, S.-E., Tornéus, C., Wiik, L. and Visavi AB,** *Bekämpning i praktiken –jordbruk, trädgård och skog*, Natur och kultur fakta, WS Bookwell, Finland, p. 64-85.

Sarfraz, M., Keddie, A.B., Dosdall, L.M. (2005), Biological control of the diamondback moth, *Plutella xylostella*: A review, *Biocontrol Science and Technology*, 15 (8): 763-789.

Shah, P.A., Clark, S.J., Pell, J. (2004), Assessment of aphid host range and isolate variability in *Pandora neoaphidis* (Zygomycetes: Entomophthorales), *Biological Control*, 29 (1): 90-99.

Smith, L. A. and Thomson, S. J. (2003), United States Department of Agriculture - Agricultural Research Service: Research in application technology for pest management, *Pest Management Science*, vol. 59: p. 699-707

Säll, C. (1996), Kålgallmyggan, *Faktablad om växtskydd: Trädgård*, (150T), Sveriges Lantbruksuniversitet, Uppsala

Säll, C. (2006), Nya kålsorter klarar klumprotsjuka, *Viola*, *Potatis & Grönsaker*, no. 20, p. 34

Takada, Y., Kawamura, S., Tanaka, T. (2000), Biological characteristics: growth and development of the egg parasitoid *Trichogramma dendrolimi* (Hymenoptera: Trichogrammatidae) on the cabbage armyworm *Mamestra brassicae* (Lepidoptera: Noctuidae), *Appl. Entomol. Zool.*, 35 (3): 369-379.

Wallenhammar, A-C. (1996), Prevalence of *Plasmodiophora brassicae* in a spring oilseed rape growing area in central Sweden and factors influencing soil infestation levels, Plant Pathology, vol. 45: p. 710-719

Wallenhammar, A-C. (1997), Klumprotsjuka på kålväxter, *Faktablad om växtskydd: Trädgård*, (119T), Sveriges Lantbruksuniversitet, Uppsala

Wallenhammar, A-C. (1999), Monitoring and Control of *Plasmodiophora brassicae* in spring Oilseed Brassica Crops, *Acta Universitatis Agriculturae sueciae, Agraria* vol. 183: 54 pp

Weidow, B (2000), *Ogräs på åker och i trädgård.* Almqvist & Wiksell Tryckeri AB, Uppsala. p. 6-7, 48, 52, 60, 78

Zhang, W.Q., Hassan, S.A. (2003), Use of the parasitoid *Diaeretiella rapae* (McIntoch) to control the cabbage aphid *Brevicoryne brassicae* (L.), *Journal of applied entomology*, 127: 522-526.