Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Fakulteten för landskapsplanering,
trädgårds– och jordbruksvetenskap

Apple sawfly (*Hoplocampa testudinea*, Klug) situation, forecasting, monitoring and use of extract from *Quassia amara* for controlling the apple sawfly in organic apple orchards in Sweden

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Title

Äpplestekeln (*Hoplocampa testudinea*, Klug): läget i Sverige, prognos, övervakning samt bekämpning med *Quassia amara* extrakt mot äpplestekeln i svenska äppelodlingar

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Foreword

This is a degree to be submitted to the Faculty of Landscape Planning, Horticulture and Agricultural Science in partial fulfillment for the requirement of the degree of Agroecology – Master's programme at the Swedish University of Agricultural Sciences, Alnarp.

I visited an organic apple orchard for a group assignment during the course "Agroecology Basics" on September 2010. That visit motivated me to acquire more knowledge about organic production. Later on, I wrote a report about crop protection in organic apples for the course "Ecology of Production Systems" based on what I had gained through the farm visit. I must say these two incidents arouse my interest to do this research project related to organic production. I got an opportunity to work for this research project with help of Professor Birgitta Rämert. Without her support, this thesis would not have been possible.

This thesis has been a learning process. I have gained an immense knowledge about plant protection in organic production and also different agroecological aspects. I have also been educated to work in a group and learnt about the importance of participation of different stakeholders for success in any project. I believe it will be an important step in my personal as well as professional development in future. I have tried to perform better under my supervisors Weronika Swiergiel and Patrick Sjöberg. Both quantitative and qualitative methods have been used to collect data, for instance, field trial as well as semi structured face to face interviews were conducted for the project.

Acknowledgement

My sincere gratitude goes to my great supervisors Weronika Swiergiel and Patrick Sjöberg for being so helpful and cooperative who always were ready to suggest and guide me throughout the entire period of the research. I would like to extend thanks to the Department of Plant Protection Biology for providing an opportunity to carry out this thesis and for cooperation during the research period. A lot of thanks also go to organic apple growers Anders Månsson, Jörgen Nilsson, Per Christer Odén, Kalle Johansson, Marta Johansson and Göte Svensson within the participatory research programme who were so much generous and provided plenty of information during the interviews. I would like to express my appreciation to an advisor from Äppelriket, Henrik Stridh for giving his time for the interview. I cannot forget to mention Jan Eric Englund for his guidance regarding the use of statistics. I am very grateful to our Master's Thesis course coordinator Christina Kolstrup for her support during the course and many thanks to her. Similarly, a lot of appreciation goes to Märit Jansson and Johan Ascard for their valuable information.

I would like to remember my family and friends for their moral support as well as inspiration during the study period.

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Abstract

The main objective of the thesis was to find out the growers' perspective towards the problem of apple sawfly (*Hoplocampa testudinea,* Klug) as well as its solution, evaluate the suitability of Dutch and Swiss forecasting methods in Swedish environment, and evaluate the efficiency and timing of Quassia extract application with varying concentration of rapeseed oil product Zence 40 against the apple sawfly. The apple sawfly was monitored using white sticky traps in two orchards located in Alnarp and Malmö. The forecasting models for emergence of first sawfly (Dutch model) and egg hatch (Swiss model) were combined and used for determining timing of Quassia extract application. The model worked well for forecasting both the first emergence and egg hatch of the apple sawfly. A field trial was conducted for spraying Quassia extract as a control measure against the apple sawfly. The treatments were 1) Petal fall (PF), 2) Day degree low zence (DDL), 3), Day degree high zence (DDH) and 4) Control (C). The dose of Quassia was used at 12 kg per hectare in 400 liters of water. The percentage of the apple sawfly damage was significantly lower in all treatments compared to control with 3.8%, 3.2%, 2.9% and 9.9 % damage in treatment 1, 2, 3 and 4. There was no difference in secondary damage between treatments. This could have been influenced by a large aphid infestation at that time. Semi structured face to face interviews were carried out to get deeper understanding of the problem. Older orchards were found to have relatively more infestation compared to new orchards. The growers were interested to continue the work with monitoring and trap catches in the coming season. They wished that the model should be proposed which can be used by the advisors from Äppelriket and the Board of Agriculture for forecasting the apple sawfly in Sweden.

Key words: Apple sawfly, *Hoplocampa testudinea*, Quassia extract, *Quassia amara*, forecasting, day degree model, semi structured interview.

Abbreviations

IP	Integrated Production
IPM	Integrated Pest Management
SLU	Sveriges Lantbruksuniversitet
IFOAM	International Federation of Organic Agriculture Movement
dd	Day degrees
PRA	Participatory Rural Appraisal
NGO	Non-Governmental Organization
T	Treatment
PF	Petal fall
DDL	Day Degree Low Zence
DDH	Day Degree High Zence
SJV	[Svenska] Jordbruksverket

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1. Introduction

1.1 Background

In Sweden, conventional growing, integrated production (IP) and organic growing are generally practiced for apple cultivation. Many Swedish growers have changed their pattern of growing from conventional to IP but only few steps are taken to start organic apple production (Jönsson, 2007). At the present situation, there is a burgeoning consumer interest in organic fruits (Zehnder *et al.*, 2007). Jönsson (2007) also said that pests, diseases and weeds can cause severe problems in organic orchards. This limits the production of organic apples because of high degree of risks faced by the growers.

This thesis is based on my interest on plant protection in organic production and also on the interest shown by integrated and organic growers in a meeting with researchers from Swedish University of Agricultural Sciences (SLU) discussing current and future research (pers. comm. Swiergiel, 2011). The growers wished to have a forecasting model for the apple sawfly. The meeting was held on the 10^{th} of February 2011. Organic growers in a participatory research group working on integrated pest management strategies in organic apple production also showed interest. They wished to know more about proper preparation, application and the efficacy of a botanical insecticide Quassia based on the bark of a shrub *Quassia amara*.

1.2 Aim

The aim of the research was to learn about the problem of the apple sawfly, *Hoplocampa testudinea* (Klug) in Swedish organic apple orchards and to evaluate the effectiveness and proper timing of Quassia extract application against the pest, *Hoplocampa testudinea* in an experimental apple orchard based on the forecasting model developed by Zijp & Bloomers in Netherlands and Graf *et al* in Switzerland.

1.3 Literature review

1.3.1 Apple cultivation in Sweden

Apple is a fruit cultivated in temperate parts of the world. The apple *Malus domestica* belongs to the family Rosaceae and subfamily Maloideae (Currie, 2000). In the genus *Malus*, there are about 25 to 30 species. In the middle of Sweden (Grönsöö), apple growing has been authenticated for around 400 years. During the 16^{th} and 17^{th} centuries, the Swedish kings encouraged the growing of fruits in Sweden. The king's deed was followed by the noblemen as they started planting fruits around their manor houses and castles. Later on the church and the priests played a vital role for spreading the fruit growing knowledge to the society (Nilsson, 1986).

The major apple growing is situated in the Southern Sweden especially around the village Kivik in 10-50 ha orchards (Jönsson, 2007) and Vånga in the north-east of Kristianstad (pers. comm., Swiergiel, 2011). Out of the total fruits produced in Sweden, apples constitute 85 % (Ascard *et al.*, 2010). In 2005, the total apple yield was 17,683 tonnes from 1440 hectares of land. In 2010, the total production (both conventional and organic) of apples was 23,500 tonnes. The production has increased in a span of five years. It is also an increment of 12 % as compared to 2009 (Jordbruksverket, 2010). The area of organic apple is increasing and there is an approximately 130 hectares of organic apple production (pers. comm., Ascard, 2011). But the overall yield of organic apples is not satisfactory (pers. comm., Stridh, 2011).

In Sweden, there is an organization accredited by International Federation for Organic Agriculture Movement (IFOAM) that regulates organic production. This organization is known as KRAV. It updates and follows the rules and regulations set up by IFOAM (Sandskär, 2003). It also adapts the rules since some rules are stricter than IFOAM. The goal of IFOAM is to adopt ecologic, social and economic systems worldwide based on the principles of organic agriculture (IFOAM, 2009). The Swedish Agricultural Policy considers organic agriculture to be very potential for meeting its national environmental objectives and the government is promoting it (Ascard *et al*., 2010).

1.3.2 Apple sawfly taxonomy and morphology

Apple sawfly (*Hoplocampa testudinea*) is an apple pest that belongs to the order Hymenoptera and family Tenthrinideae. Adults are 6 to 7 mm in length and the body is pale fulvous brown or orange with black and shining thorax and abdomen (Miles, 1932). Wings are generally more or less clear with dark brown veins (Fig. 1). The egg is oval, colorless, shiny and 0.8 mm in length (Alford, 1984). In about four to six weeks, the larvae become mature. A mature larva measures about 9-11 mm long with yellowish brown head and white colored body (Fig.1). In early instars, the head is shining black at the vertex and pale on the facial region (Miles, 1932).

Fig.1 Apple sawfly adult (Photo: Weronika Swiergiel) and larva (Photo: Dipesh Neupane)

1.3.3 Apple sawfly biology

The apple sawfly *Hoplocampa testudinea* is a serious pest in commercial apple orchards (Alford, 1984) in Europe and North America (Graf *et al*., 1996a). Significant damages have been found in organic apple orchards in Europe as a result of apple sawfly (Zjip & Bloomers, 2002a; Kienzle *et al*., 2006a). It has only one brood per annum (Miles, 1932). It remains as a prepupa within a cocoon in the soil. Diapause can sometimes last up to three years (Zjip & Bloomers, 1993). The sawfly pupa hatches and emerges around the blooming period of early and moderately early varieties (Zjip & Bloomers, 1993) such as Rubinola, Discovery, etc. The male and female sawflies copulate within the first hours of emergence (Böhm, 1952; Graf *et al*., 2001). The apple sawflies need relatively warm and sunny weather with a lower thermal threshold of about 11°C for reproduction (Graf *et al*., 2001). The female sawfly lays egg singly on the receptacle of the flowers below the ring of sepals by a saw-like ovipositor (Alford, 1984). The female sawfly makes a small slit like cut on the receptacle with its ovipositor and egg is inserted inside. A sawfly female can lay an average 32 eggs ranging from 5-103 eggs in its life period (Dicker, 1953). The incubation period of eggs of apple sawfly is 14-15 days at a temperature of 11-15°C.

The larvae tunnel into the fruits and start to destroy developing fruitlets. The larva which tunnels to the ovary usually reaches the third instar by that time. Full grown fifth instar larvae abandon the fruit and start spinning the cocoon in which they hibernate inside the soil (Miles, 1932). The larva begins its hibernation from June to the following spring (April or May). The larva can hibernate approximately at a depth of 8-23 centimeters (3-9 inches) under the soil and even below this depth.

Graf *et al* (1996a) stated that the apple sawfly comes out of the soil at the same time when the early apple varieties begin to flower which establishes a link between the reproductive period of the apple sawfly and the phenological stages of the varieties. This coincidence is a prerequisite for infestation (Graf *et al.,* 2001). Soil temperature determines the spring emergence of the sawfly adults (Graf *et al*., 1996a). In the past, the biology of the apple sawfly has been studied and analyzed to find out effective control measures for the sawfly problem (Miles, 1932., Dicker 1953). Field trials were conducted from 1949-1951 to find out the effect of spraying on different timings such as 80% petal fall, 50% egg hatch and full egg hatch (Dicker, 1953).

1.3.4 Forecasting of emergence, flight period and egg hatching of the apple sawfly

Graf *et al* (1996a) developed a soil temperature driven phenology model to predict the flight period in a study carried out in Switzerland. The minimum threshold for post diapause development of the apple sawfly was found to be 4.5°C. The minimum threshold is the minimum temperature below which no growth occurs. The day degree (average temperature sum) model has also been developed for forecasting emergence and egg hatching of the apple sawfly. This model was developed by Zjip and Bloomers from Netherlands in 1997. A sum of degree days is the total amount of heat that is required for the development of an organism from one point to another point in the life cycle (University of California, 2003). Zjip and Bloomers (1997) recommended that white sticky traps should be installed in the apple orchards at an accumulative value of 157 day degrees when calculated from 15th March with minimum threshold of 4°C. The day degree model uses the daily average air temperature and the threshold temperature for the apple sawfly. The same author furthermore stated that the first emergence of the apple sawfly can be seen within a range of 177±10 day degrees (Table 1). Zjip and Bloomers (1997) observed similar deviations between the mean air temperature sum and the mean soil temperature sum. It implies that air temperature can also be used to predict the emergence of the first sawfly. Most private weather station measure only air temperature.

The apple sawfly adults are generally monitored using white sticky traps. White surfaces that do not reflect the ultraviolet light attract the apple sawfly as it considers those white surfaces to be blossoms (Owens & Prokopy, 1978; Andermatt Biocontrol, 2011). Monitoring method focusing on white sticky traps has been carried out in different countries in the past years (Owens & Prokopy, 1978; Wildbolz & Staub, 1986; Graf *et al.*, 1996a). White sticky rectangular traps captured more sawfly adults compared to other surfaces such as blue, red, orange, green, yellow, and black enamels (Owens & Prokopy, 1978). Traps installed in the upper portion of the trees captured more sawflies than lower part (Wildbolz & Staub, 1986).

Graf *et al* (2002) developed a forecasting model which predicts when the eggs of the apple sawfly hatch into first instar larvae. The model explained that egg hatching of the apple sawfly is generally observed at a thermal constant of 85 day degrees with a threshold temperature of 6.9°C from the period when the eggs are laid. The thermal threshold temperature for egg development is greater than the post diapause development of the apple sawfly. It is based on the fact that temperature requirement for post diapause developmental stage is lower as compared to stages during the egg development (Zjip & Bloomers, 1997).

The forecasting of either pests or even diseases can be very important from both environmental as well as economic point of view. It reduces the amount of synthetic chemicals such as pesticides, fungicides, etc. going into the environment. This will eventually lead to a lower cost of application for the growers (Zehnder *et al.*, 2007). The forecasting system can reduce the damage level. Along with the forecasting, a regular monitoring is also needed to check the damage threshold level. The threshold of damage is a level after which if the control measures are not applied, it causes economic damage to the grower.

Table 1. Different steps with recommended day degrees and minimum threshold

Steps	Recommended day degrees (dd)	Minimum threshold
1. Installation of white sticky traps	157 dd from 15th of March	4°C
2.First trap catch	177±10 dd from 15th of March	4°C
3.Egg hatching	85 dd from egg laying	6.9°C

1.3.5 Apple sawfly damage

Miles (1932) distinguished two types of damage to the fruitlets caused by the apple sawfly: primary damage by the first and second instar larvae and secondary damage by the older larvae.

- **Primary damage -** Miles (1932) said that the young larva attempts to enter the fruit within the calyx ring and makes a tunnel to reach the ovary. This tunnel made by the larva may or may not reach the ovary. During the time of attack, the fruits are getting bigger rapidly which splits along the tunnel. This usually results into winding brown ribbon like scars on the fruitlets. The author also explained that the larva fails to reach the ovary in many cases. Those fruits possess the ribbon scar when become mature. If the larva reaches the ovary, it feeds on the developing seeds and the fruit is usually dropped on the ground.

- **Secondary damage -** The larva usually moves to another fruit in the cluster after about fortnight of entering into the fruit (Miles, 1932). While migrating from one fruit to another, the entrance hole with 1.5 mm diameter made by the larva is usually observed with wet reddish brown frass. Weires (1991) states that this insect excrement or frass gives unsightly appearance when it drops off on the adjacent fruits and leaves in the cluster. The secondary damage of apple sawfly can cause the fruits to drop or fall on the ground.

During its development period, one sawfly larva can show its destructive potential by infesting up to four apples. Sometimes the injury caused by the apple sawfly larva is mistaken for the injury by the codding moth larva (Alford, 1984). The distinguishing characteristic between the damage caused by apple sawfly and coddling moth is that the excrement of the apple coddling moth (*Cydia pomonella* L.) is completely dry and odorless (Ascard & Juhlin, 2011). Another difference between the two insects is that apple sawfly infests early cultivars while the coddling moth damages the late cultivars severely as compared to early ones (Ohlendorf, 1999).

Fig. 2 Primary damage and Secondary damage from apple sawfly (Photo: Dipesh Neupane)

1.3.6 Natural enemies of the apple sawfly

Natural enemies are responsible for the biological control of pests. Eilenberg *et al* (2001) defined biological control as "*The use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be".* These organisms play an important role for pest control in organic production (Sandskär, 2003). In organic apple production, the apple sawfly can be controlled by using natural enemies such as parasitoids, entomophagous fungi and entomogenous nematodes (Cross *et al*., 1999a, b).

Lathrolestes ensator (Brauns) is a parasitoid of the apple sawfly larvae and it is host specific (Zjip & Bloomers, 1993). *L. ensator* chooses to attack second instar host larvae over other larval stage (Babendreier, 1996). Zjip & Bloomers (2002b) showed that the eggs are black and can be visible through the larval skin. These eggs hatch after the host larva forms cocoon in the soil. The parasitoid larva forms a filmy cocoon around the sawfly cocoon.

A study carried out in Switzerland discovered an important natural agent the parasitoid *Aptesis nigrocincta* (Gravenhorst) that can be used against the apple sawfly in organic apple growing. It parasitizes the cocoons of the apple sawfly in the soil. It has two generations per year. Females of *A. nigrocincta* parasitize the host cocoons in the soil at a depth of 10-25cm (Babendreier, 2000). The study demonstrated 12.1% to 39.7% parasitism of *A. nigrocincta* on the apple sawfly cocoons.

A literature review performed by Jaworska and her own results (1992) showed 100% mortality of the apple sawfly in the laboratory as a result of fungal diseases. Larvae parasitized by *L. ensator* before the formation of cocoons are more prone to attack by fungal diseases than other unparasitized larvae and parasitoids inside the cocoons (Jaworska, 1987). Jaworska (1979) established the most aggressive species of fungi as *Paecillomyces* spp. because of high mortality rate of the apple sawfly. These fungi species are now named *Isaria*. These findings are also supported by Graf *et al* (1995) which revealed that about 40% mortality was caused due to fungal infection of *Paecillomyces farinosus.*

Vincent & B**é**lair (1992) showed that strains of entomopathogenic nematodes such as *Steinernema carpocapsae*, *Steinernema feltiae*, *Heterorhabditis bacteriophora*, etc. caused 100% mortality in the laboratory after 72 hours of treatment. The application of all those strains yielded promising results up to 80% mortality under semi-field condition. In other experiment performed by B**é**lair *et al* (1998), foliar sprays of *S. carpocapsae* showed significant reduction of primary damage by the apple sawfly but did not reduce secondary damage. The authors also stated that high cost of application at that time and inconsistent result rule out the possibility of using nematode foliar spray as a sole control technique against the apple sawfly.

1.3.7 *Quassia amara*

Quassia amara (Family Simaroubaceae) is a traditional medicinal plant well known for its bitter properties (Ocampo *et al*., 2010). This shrub is indigenous to the tropical region of the world, especially South America (Crompton & Tikasingh, 2005). In the past, *Q. amara* was widely used as a botanical insecticide before synthetic insecticides were developed (Kienzle *et al*., 2002). Quassin and neoquassin are the main active compounds found in *Q. amara*. Quassin is the most important among these two compounds. The mechanism of action is by ingestion, not by contact (Kienzle *et al*., 2004). The bitter compounds are present in the wood, bark and seeds of *Q. amara*. These bitter compounds (both quassin and neoquassin) are also known as quassinoids. The amount of quassinoids varies generally between 0.14-0.28 percent depending upon the age of the wood (Villalobos *et al.*, 1999). *Q. amara* wood and barks are also recognized as a measure of pest control in the international market because of insecticidal properties (Ocampo *et al*., 2010). Quassinoids are considered to be the main constituents that are responsible for biological and pharmacological properties in this family.

Key uses

Traditionally, people used *Q. amara* for medicinal purposes such as restoring loss of appetite and for diabetes. Bitter tonic prepared by soaking the wood chips in either wine or water was used for this purpose. The infusion made by putting the roots overnight in water was taken as a remedy for fevers. Commercially, the extract prepared from *Q. amara* wood chips is now being used widely as food flavourants in beverages, baked goods and certain laxative medications (Crompton & Tikasingh, 2005).

Safety and regulatory framework

Kienzle *et al* (2004) tested the side effects of Quassia extract on the beneficial arthropods such as *Aphelinus mali* (parasitoid wasp), *Chrysopa carnea* (Green lacewing), *Coccinella septempunctata* (Ladybird beetle), *Aphidius rhopalosiphi* (Parasitoid) and *Forficula auricularia* (Earwig) by the contact and oral toxicity. These organisms have the negligible side effects of Quassia extract at recommended field rate (12g/ha). Their results showed the mortality of about 30%. Vogt (2001) also observed that residual contact as well as direct spraying of Quassia extract did not harm *C. carnea* in laboratory tests. There was a slight increase in the mortality (3.3-33.1%) in larval tests but no mortality occurred in the adults. The Council of Europe and the international regulatory agencies have considered the Quassia safe for using as food flavourants at dose not exceeding 5mg/kg body mass (Ocampo *et al*., 2010). KRAV allows the use of Quassia against the apple sawfly in organic apple production (Ascard & Juhlin, 2011). The author furthermore stated that Quassia is not registered as pesticide in Sweden but the organic growers can prepare and apply the extract of Quassia for their own use. Quassia is also permitted to use against the sawfly under EU regulations.

1.3.8 Participatory Rural Appraisal

"*Participatory rural appraisal (PRA) describes a growing family of approaches and methods to enable local people to share, enhance and analyze their knowledge of life and conditions, to plan and to act"* (Chambers, 1994).

Different NGOs operating at grass root level first developed Participatory Rural Appraisal (PRA) in India and Kenya during 1980s (Sontheimer *et al*., 1999). PRA has evolved so fast till today in different terms such as methodology, development of new tools and the ways of application. There are different tools of PRA such as interviews, resource map, focused group discussion, transect walk, seasonal calendar, etc. that are being used in different academic disciplines.

Kvale *et al* (2009) defined an interview as an inter-view or inter-change of views between two persons about the subject matter of mutual interest. In qualitative research interview, when there is an interaction between interviewer and interviewee, knowledge regarding the subject matter is produced. The production of knowledge and data about the subject matter is dependent upon the skills of the interviewer. The interviewer must have sound knowledge of subject matter to extract quality information from the interviewee. The interviewing skills include listening very carefully and the art of posing questions to the interviewee (pers. comm. Jansson, 2011). Bernard (2006) said that interviewing concept encompasses a big boundary from totally unstructured to semi structured and also highly formal interactions. Semi structured interviews are based on a list of themes of the subject matter. They have open ended questions rather than closed ended like in questionnaires. The author also stated that face to face interview will be more efficient to collect the accurate data from the respondents.

Seasonal calendar is an important tool used in participatory rural appraisal (Sontheimer *et al*., 1999). The main objective of preparing a seasonal calendar is to find out seasonal changes in various activities such as labor, income, expenditure, etc. and to find connections between them.

Resource map is a tool that helps to know about the resource base of any community or may be any farm (Helvitas Vietnam, 2003). The main idea is to get information about the perception of local people regarding its resources**.**

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2. Materials and Methods

2.1 Phenology study

2.1.1 Calculation of day degrees

The main idea of day degree calculations was to estimate the timing for installation of white sticky traps. Climate data was gathered from automated Davis weather stations located in Lund (Glorias) and Malmö (Dammstorp) (Fig. 3). The formula used for calculating day degree is

Day degrees = (Minimum + Maximum temperature)/2 − Minimum Threshold temperature

This is known as the rectangle method of day degree calculation (University of Illinois, 2004) and it is a simple form of day degree calculation. The weather station in the Garden laboratory was not functioning and since Alnarp lies between Lund and Malmö, the day degrees for the Garden laboratory were taken as a mean of the data from both weather stations. The day degrees were calculated by subtracting the threshold temperature from the average daily temperature for each day. The cumulative value of day degrees was added till it reached the recommended value of day degree for both emergence and egg hatching of the apple sawfly. The day degree calculations were started from the 15^{th} of March.

The day degree model proposed by Zijp and Bloomers (1997) was used for forecasting adult emergence and the flight period of the sawfly adults. A lower threshold of 4°C was used for forecasting the emergence of sawfly adults while for forecasting of egg hatch, a minimum threshold of 6.9°C was applied. Trap catches were monitored daily to record the number of apple sawflies. The idea behind monitoring trap catches was to estimate the day degrees when the number of trap catches begin to peak. The calculation of day degree was started from just before the peak in order to cover maximum number of newly hatched first instar larvae while spraying.

Fig. 3 Weather station in Dammstorp, Malmö (Photo: Dipesh Neupane)

2.1.2 Installation of white sticky traps

White sticky traps of type Rebell bianco (Fig. 4) were installed at a height of about 1.5 m from the ground at an approximate distance of 30 meters spread over the whole orchard. The number of adult sawflies was counted after inspection of the traps each day during the flight period. The traps were changed daily to maintain attractiveness of the traps.

Fig. 4 White sticky traps at the Garden laboratory and Dammstorp (Photo: Dipesh Neupane)

Location 1

The Garden laboratory is situated in Alnarp (55°39'36.75''N, 13° 5'7.33''E) and traps were installed in the orchard area of 0.2 ha on the 29th April. By that time, the temperature sum was accumulated to a value of 175 day degrees. A total number of six sticky traps were placed in the apple trees in the orchard, three on cultivar Discovery and three on cultivar Amorosa.

Fig. 5 Aerial photo of experimental orchard in the Garden Laboratory (Photo: Google earth)

Location 2

Dammstorps Handelsträdgård is located at Tulipsvägen, Malmo (55°36'03.45"N, 13° 0.6'16.84"E) and traps were installed in the orchard area of 1 ha on the 29th of April. By that time, the temperature sum was accumulated to a value of 185 day degrees at Dammstorps Handelsträdgård. Seven sticky traps were installed on Rubinola trees for monitoring of the apple sawfly.

Fig. 6 Aerial photo of orchard in Dammstorps Handelsträdgård (Photo: Google earth).

2.1.3 Phenological stages

The number of trap catches corresponding to the phenological stages of the apple trees was studied for assessing the link between phenology and the reproductive period of the apple sawfly and the flowering period of the apple cultivars. The cultivars Discovery and Rubinola were chosen for studying the phenology of apple cultivars and the trees were chosen randomly. After installation of white sticky traps, pictures for the phenology study of the apple trees were taken at different periods of the flower development such as pink stage, king bloom, full bloom and petal fall stage. The pictures were taken at an interval of 3 or 4 days to keep track on the development of the apple flowers. At the same time, the number of trap catches of the adult sawflies was also recorded.

Fig.7 Phenological stages of cultivar Discovery (From left- Pink stage, King bloom, Full bloom and Petal fall stage) (Photo: Dipesh Neupane)

Fig. 8 Phenological stages of cultivar Rubinola (From left-Pink stage, King bloom, Full bloom and Petal fall stage) (Photo: Dipesh Neupane)

2.2 Field trial

2.2.1 Experimental design

The cultivar Discovery was sprayed in the experimental orchard located at the Garden laboratory in Alnarp. A randomized block design was used for the field trial. Four replications of each treatment were established. The treatments were categorized as petal fall stage (PF/T1), day degree low zence (DDL/T2), day degree high zence (DDH/T3) and control (C/T4). Each treatment in a block was marked with four different colored ribbons to identify easily for spraying. Quassia extract was applied at the petal fall stage when more than 50 % of petals fell off from the flower clusters. The 50% petal fall was assessed by regular inspection of Discovery trees in the orchard when the petals began to fall off. For day degree treatment, Quassia was sprayed when the average temperature sum crossed the recommended value of 85 day degrees for egg hatching. The edge row trees and the trees at the border of each treatment were excluded from the experiment.

2.2.2 Quassia extract preparation and spraying

Wood chips of *Quassia amara* were kept in hot water (60°C) for 24 hours. The brown colored solution was separated from the chips by the process of decantation. Decantation is a quick and easy process of separating a mixture of liquid and solid. A filter paper was used to separate the solution from the wood chips. The filter paper was used to prevent small particles of wood chips going into the nozzle of the sprayer and blocking the smooth passage of extract while spraying Quassia. Otherwise, these fine particles of Quassia chips will block the nozzle. The soap/wetting agent Zence 40 was added to the spray solution and the extract was prepared just the day before spraying. The dose of Quassia was 12kg per hectare in 400 liters of water.

Different concentrations of Zence 40 were added to the extract before spraying. Day degree low zence corresponds to 1 % Zence 40 while day degree high zence includes 2.5%. The petal fall stage treatment was sprayed on the 19th of May 2011 while day degree treatments were applied on the 21st of May 2011 in the evening time. A backpack sprayer with an electric pump was used for spraying the extract (Solo accu power 416).

Table 2. Application of Quassia extract against *Hoplocampa testudinea* in a field trial (Alnarp, 2012)

Treatments	Spraying dates	Day degrees from peak	Concentration of Zence 40	Dosage of Quassia
1. Petal fall stage (PF/T1)	19th May 2011	78.6 dd	2.5%	12 kg/ha
2. Day degree low zence (DDL/T2)	21st May 2011	89.5 dd	1%	12 kg/ha
3. Day degree high zence (DDH/T3)	21st May 2011	89.5 dd	2.5%	12 kg/ha
4. Control (C/T4)	Unsprayed			

2.3 Participatory Rural Appraisal

Semi structured face to face interviews were carried out to get qualitative information such as experience, knowledge and perception of the growers. The information gathered was used to make a rich picture of each farm, especially focusing on the problem of apple sawfly infestation. A total of five organic apple growers were interviewed at different dates on 5th, 20th, 21st October, 10th November and 7th December. The growers are participants in a participatory research project within SLU called *Development of Pest Management Strategies in Organic Apple Production in collaboration with Farmers utilizing Complementary Biological Control Strategies* (pers. comm. Swiergiel, 2011). The interviews were based on the following themes,

1. General description of the farm

2. Production and management system

3. Crop protection (Apple sawfly focus)

4. Advisory service, and

5. Marketing system.

Interviews were conducted going to the respective farm of participating growers. Some of the tools of PRA such as field walks, resource map and seasonal calendar (Sontheimer *et al*., 1999) were also used to extract the useful information from the growers. Interviews were usually started walking around the farm (apple orchard) and looking at the resources on the farm. A voice recorder was used to record the interviews. The recorded interviews were transcribed and then summarized. Interviews tried to cover organic apple growers spread over Skåne (Malmö, Kivik, Tomelilla) and Blekinge (Karlskrona). The summaries of interviews were sent back to the growers for authentication of the information. The farms were compared on the basis of those summaries of interviews. The information obtained from the grower's meeting on the 25th of August and the 15th of December, 2011 was analyzed to know their views on the monitoring method and use of Quassia extract against the apple sawfly.

Table 3. Participatory Rural Appraisal Tools

Tools	***Why***	***Description***	***When***
1. Semi structured interviews	To get broader understanding of the problem.	A face to face interview based on a list of themes.	During the farm visit.
2.Field walk	To get the farmer's view about the farm and to use it as ice breaker.	A walk around the farm along with the farmer and talking about history, farm family, production processes, etc.	Together with semi structured interview during the farm visit.
3.Resource map	To get an overview about the resources of the farm as well as what comes into and what goes out of the farm.	A map showing location of different resources of the farm. At the same time, listing the inputs and outcomes of the farm.	During the semi structured face to face interviews.
4.Seasonal calendar	To extract general idea about different farming activities all around the year and their relationship to each other and to find labor peak time in the farm.	A calendar providing the information about the activities that are carried out in the farm during different months in a year.	During the semi structured interviews.

Table 4. List of interviewees and interview sites.

Interviewees	*Name of the farm*	*Interview sites*
1.Anders Månsson	Helenlust	Tomelilla
2. Jörgen Nilsson	Dammstorps Handelsträdgård	Malmö
3. Per Christer Odén	Per Christer Odén's farm	Kivik
4. Kalle and Märta Johansson	Grönsåker Direkt	Karlskrona
5.Henrik Stridh and Göte Svensson	Äppelriket/Kiviks Musteri	Kiviks Musteri

2.4 Damage calculation

The percentage of damage was calculated by randomly choosing 3 trees from each treatment from all 4 blocks. The infested fruits included both primary and secondary damage caused by the apple sawfly. The damage evaluation was done twice, first for primary damage (30/5/2011) and second for secondary damage (15/6/2011) on the same trees. The total number of fruits per tree and the number of infested fruits per tree was counted. Then, the percentage of damage for each treatment in each block was calculated.

2.5 Statistical analysis

Minitab 16 was used as statistical software. Analysis of variance (ANOVA) was used to evaluate the experimental data statistically and Tukey's test was used to determine statistical differences among the treatments.

3. Result

3.1 Phenology study

3.1.1 Garden laboratory - In Discovery, the first emergence of sawfly was observed when the temperature sum reached a value of 186-191 day degrees with a lower threshold of 4° C. The temperature sum was calculated from the 5^{th} of May for forecasting egg hatch. The temperature sum reached a value of 89.5 day degrees on the 21^{st} of May with a lower threshold of 6.9°C. The flight period started from 1^{st} of May in the Garden lab while it almost ended with petal fall stage.

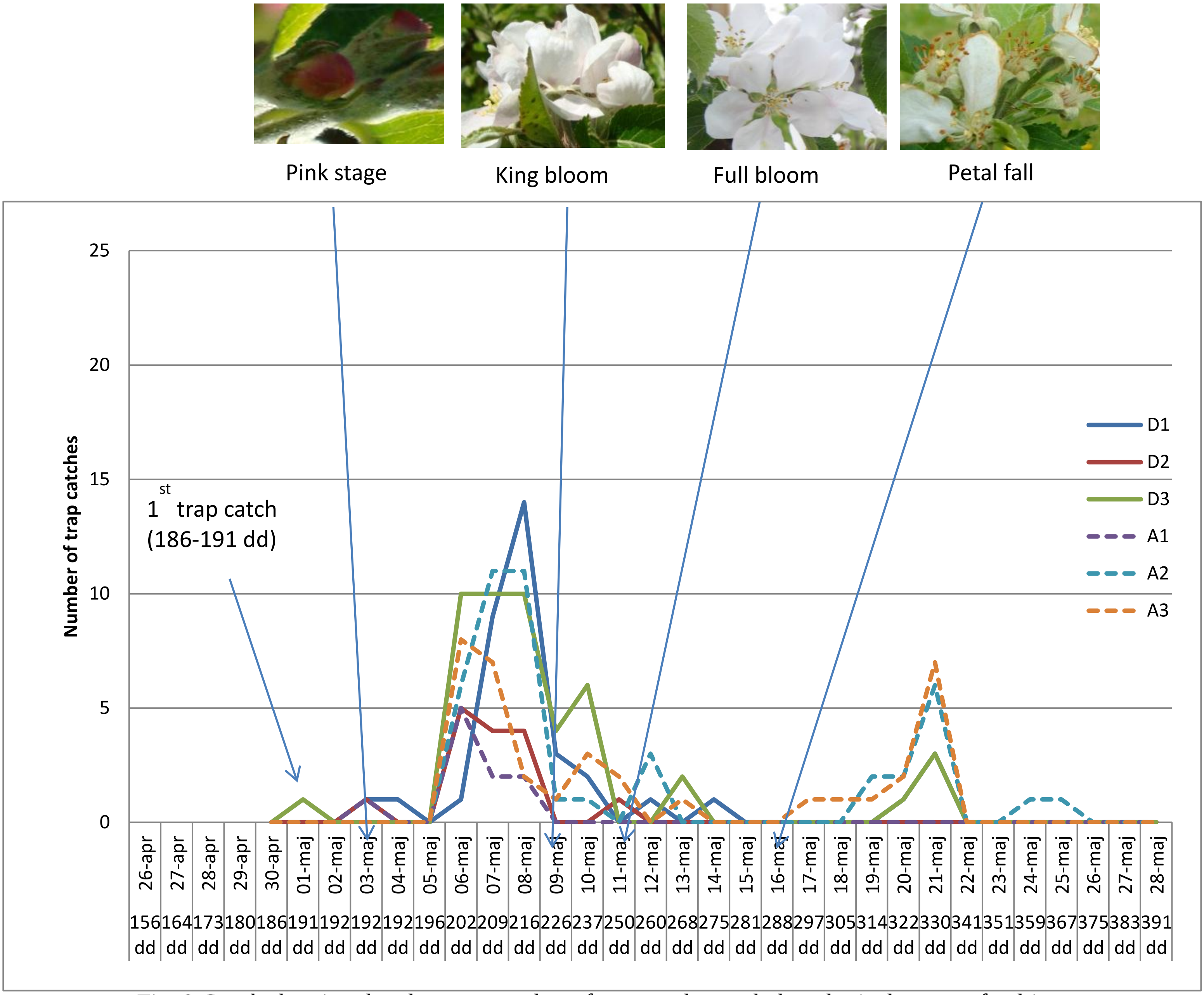

Fig. 9 Graph showing day degrees, number of trap catches and phenological stages of cultivar Discovery. Each line represents one white sticky trap installed. D- Discovery (straight lines) and A- Amorosa (dotted lines).

3.1.2 Dammstorps Handelsträdgård - In Rubinola, the first trap catch was obtained when the accumulative value of day degrees was 185-192 dd. The flight period commenced on the 30th of April and lasted till few days after the petal fall. The trend of trap catches declined when petals started to fall on the ground.

Pink stage

King bloom

Full bloom

Petal fall

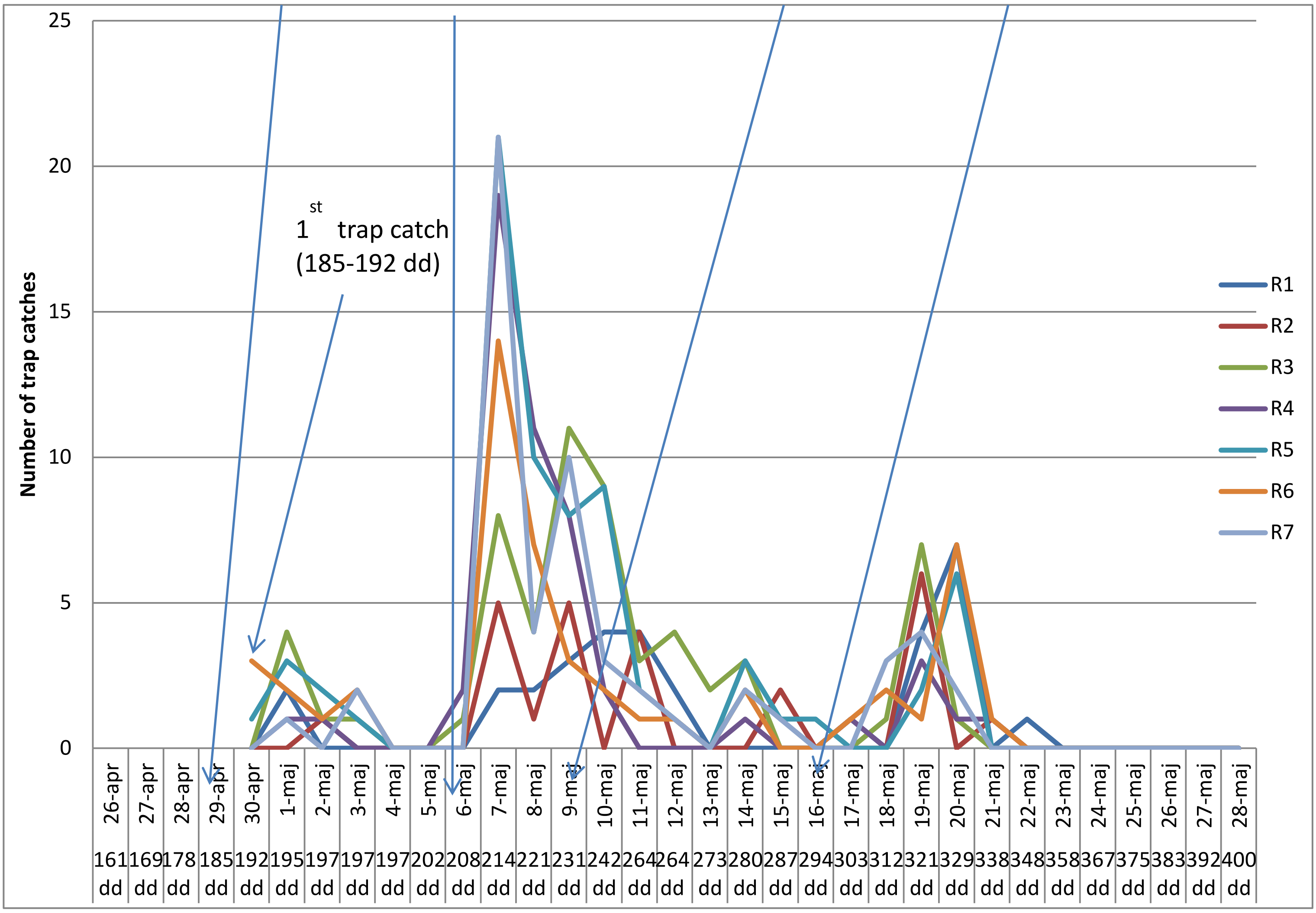

Fig. 10 Graph showing day degrees, number of trap catches and phenological stages of cultivar Rubinola (R). Each line represents one white sticky trap installed.

3.2 Field trial (Garden laboratory- Treatment with Quassia)

3.2.1 Primary damage- The evaluation of primary damage showed that treatments were significantly different from the control. But there was no difference between the treatments. The figures for infestation are 3.8 %, 3.2%, 2.9% and 9.9% for Petal fall (PF), Day degree low zence (DDL/T2), Day degree high zence (DDH/T3) and Control (C/T4) respectively.

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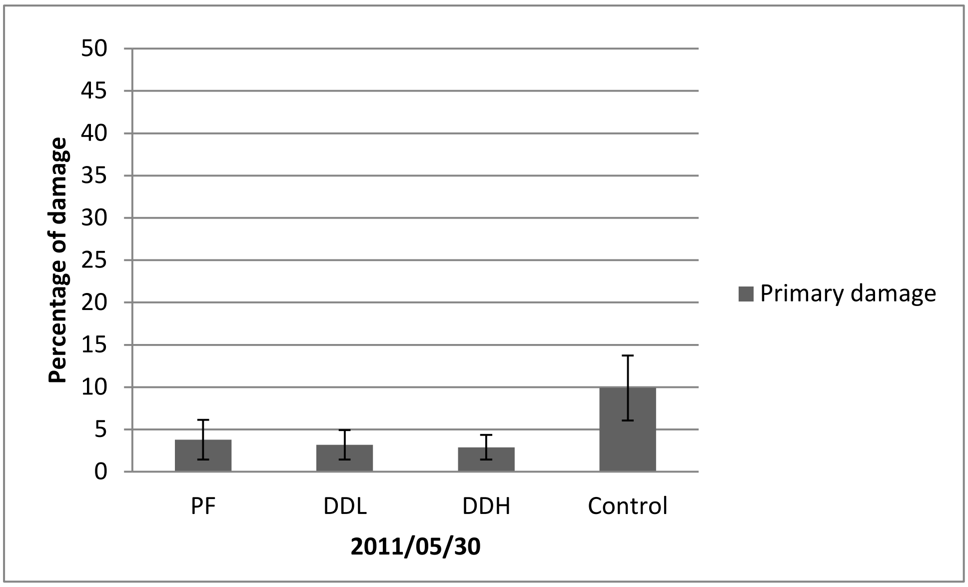

Fig. 11 Primary damage caused by the apple sawfly (Discovery)

3.2.2 Secondary damage-For secondary damage, no significant difference was found between treatments as well as between treatments and control. The infestation level increased to 10.1%, 7.2%, 7.3%, and 13.9% for PF, DDL, DDH and C respectively when secondary damage was assessed.

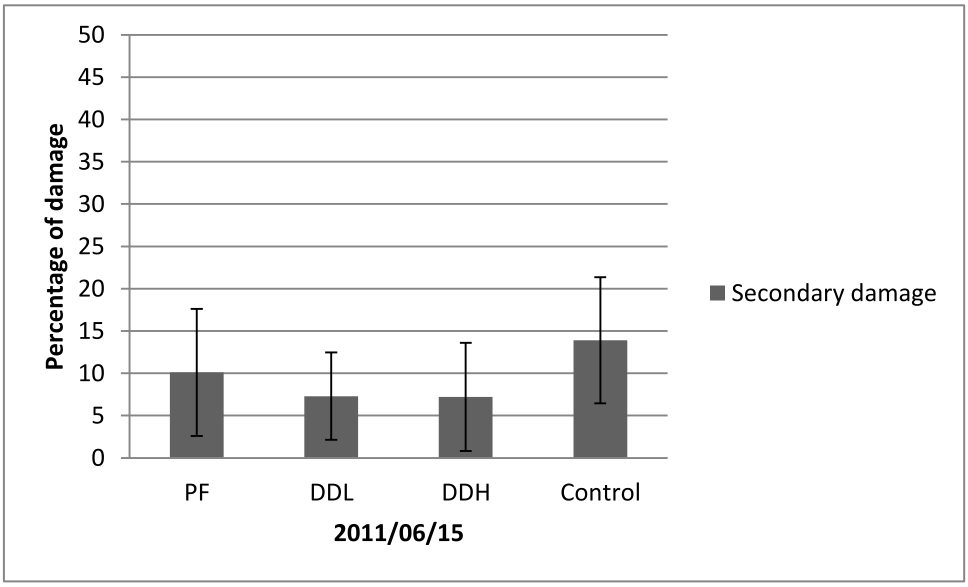

Fig. 12 Secondary damage by the apple sawfly (Discovery)

3.3 Participatory Rural Appraisal

A. Farm 1 (Helenelust)

The farm is organic and located in Tomelilla. It produces apple, juice, barely, winter wheat (flour), wool and hides from sheep. The total area of the farm is around 30 hectares while the organic apple orchard is approximately 2 ha with five cultivars such as Collina, Rubinola, Frida, Aroma and Santana. The orchard was planted in 2007. There are also some apple growers in a village several hundred meters away. Soil is clayey. Biofer (early and late) is applied as fertilizer. Foliar spray of micronutrients such as Mn, Zn and B is done. Aphids, coddling moth, winter moth, and apple sawfly are pests prevalent in the orchard. Aphids are the most important pests in the orchard. Disease like canker (*Neonectria galligena*) is present in Amorosa and Frida to some extent. Sulphur is used against scab as preventive measure. Quassia is used for both aphids and apple sawfly. Pheromone dispensers and Madex against coddling moth are used. Labor is hired only for picking apples. All apples are sold through Äppelriket while other products are sold from the farmer's market and from the farm as well. An advisor from Äppelriket helps the grower to solve the problems in the orchard. His future plan is to make a cold storage for apples. To get good apples without many damages is the challenge to the grower.

B. Farm 2 (Dammstorps Handelsträdgård)

The farm is located in Dammstorp, Malmö. The farm produces organic apples and pot flowers. Recently, they started producing organic flowers as well. Flowers are grown in the greenhouses. The orchard covers an area of 1 ha and was established in 2004. Rubinola and Santana are two cultivars of apple being grown. Although there is no other apple grower nearby, there are some old apple trees in the home garden which could be a potential source of pests and diseases. Soil is clayey with good water holding capacity. Biofer is used as fertilizer. The farm has problem with aphids, coddling moth and apple sawfly. There is severe infestation of apple sawfly in the orchard. Coddling moth and apple sawfly are the important pests for the grower. Diseases such as scab (*Venturia inequalis*) and powdery mildew (*Podosphaera leucotricha)* are often noticed in the orchard. Forecasting system against scab is used and sulphur is sprayed. Pheromones dispensers and pheromone traps are used for mating disruption against coddling moth. White sticky traps are used for monitoring of the adult sawflies and Quassia is sprayed against them. Natural enemies such as gall midge are released against aphids in the orchard. Marketing of apples is done through Äppelriket which also gives technical advices to the grower. Flowers are mainly sold through a company named MästerGrön but some customers come to the farm themselves for flowers. Pests are the biggest challenge to the grower.

C. Farm 3 (Per Christer Odén's farm)

The farm is located in Kivik. The orchard is organic and established in May 2010. Rubinola and Santana are two cultivars planted in 2.5 ha. The farm is situated in an area with intense apple production although there are a few hundred meters to the closest neighbouring apple orchard. Soil is mostly sandy with little clay and not very fertile. The grower uses compost manure for increasing the fertility of the soil. Pelleted potassium and magnesium are also used as organic fertilizers. Aphids, coddling moth and noctuid are few pests that have been noticed so far in the orchard. The important pests in the orchards are mainly aphids. Canker (*Neonectria galligena*) and powdery mildew (*Podosphaera leucotricha*) are diseases seen in the orchard. A warning system for scab (RIMpro) is used. Raptol (a mixture of rapeseed oil and pyrethroids) is used against aphids. Only sulphur (Kumulus) is usually applied against fungal diseases. No problem of apple sawfly has been found yet. They have quite a lot of bird damages. Per with the help of his wife Susanne work at the farm and there is no need of external labor. The farm is affiliated to Äppelriket which does sorting, packing and marketing of apples. It also provides advisory service to the grower. Weeds are the main challenges to the grower. The future plan is to extend apple production area up to 7.5 hectares approximately.

D. Farm 4 (Grönsaker Direkt)

The farm is situated in Blekinge. It mainly produces organic vegetables such as carrots, potatoes, Jerusalem artichoke, and special package of vegetables (onion, garlic, parsley). The total area of the farm is 40 ha while the organic apple orchard is 1.5 ha. The farm is near the sea. Very strong wind blows from the sea across the farm. Amorosa, Rubinola, Santana and Frida are four different apple cultivars being grown along with a cultivar Concorde (Pear) in the orchard. There are no other fruits orchards nearby however there are some old apple trees close to the house. Soil is very good clayey rich with organic matter. They will stop applying nitrogen because the trees are growing too much. They use biofer but from next year they will use slurry. Aphids, coddling moth, apple sawfly, some tortricids and leaf rollers are seen in the orchard but the problem is not so big. There is not so much infestation of the apple sawfly. They have their own weather station for forecasting against scab. They hire some people from April to October for full time and in the end of June for weeding in the carrots. They also get some help from their parents like Marta's father and Kalle's grandmother also work in the farm. They have just started producing their own apple juice on their farm. Some part of apple production goes to Äppelriket and some along with other vegetables are sold from the home shop and through home deliveries. 80% of carrot is sold to a company. They also get technical advice from Äppelriket. They also get some advice from KRAV and from the same company who buys their carrots. But mostly they manage the farm on their own taking help from internet and so on. In the future, they are planning to expand their apple cultivation up to 10 hectares.

E. Farm 5 (Kiviks Musteri)

Kiviks Musteri is a processing industry of apples that produces juice, jelly, marmalade, wine, etc. It is located in Kivik near to the coast. Apples are grown in the orchard with an area of 12 ha. Out of 12 ha, 3.6 ha are IPM grown and the remaining is organic production. Soil is clayey with some sand. Mushroom compost is used as fertilizer. Rubinola, James grieve, Green sleeve, Gloster and others are some cultivars grown in the orchard. The orchard has problem with pests such as aphids, coddling moth, and summer leaf rollers**.** Coddling moth and aphids are the main pests in the orchard. Forecasting system is used for scab and sulphur is sprayed against scab. Plant protection and weed problem are the major challenges of the farm. Some people are hired during summer for labor. All apples produced are used by the processing industry.

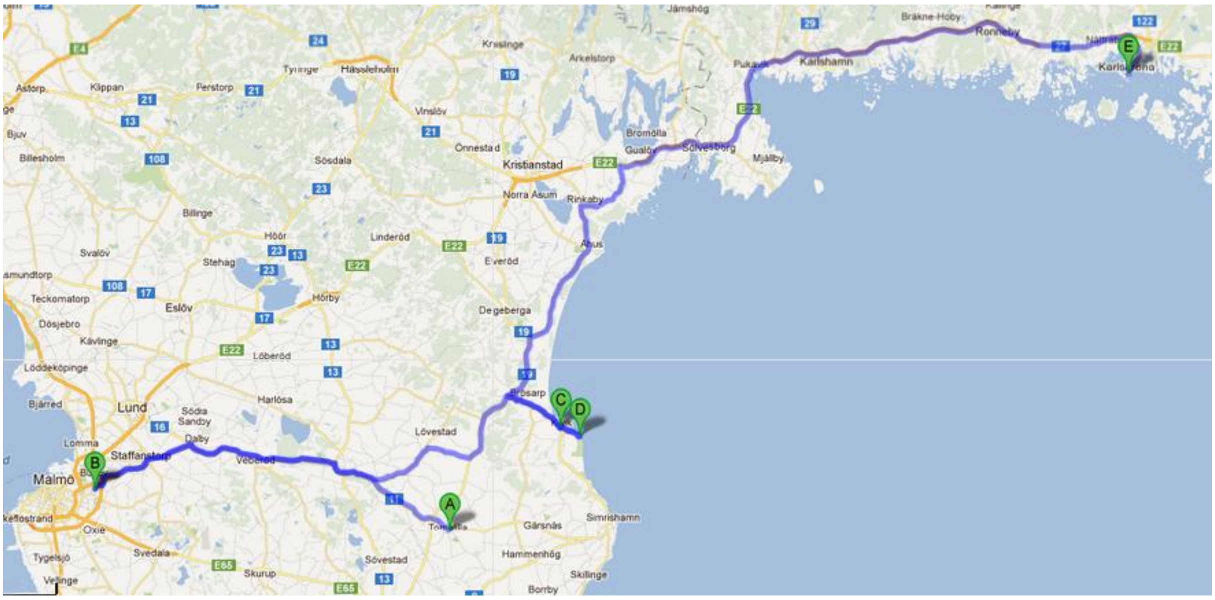

Fig. 13 Interview sites A-Tomelilla, B-Dammstorp, C-Kivik, D-Kiviks Musteri and E-Karlskrona (Photo: Google map).

With the information gathered from interviews, it is observed that the problem of sawfly infestation is relatively lower in young orchards as compared to old orchards. For instance, Dammstorp which is the oldest orchard in the participatory group has severe infection of the sawfly. It is also noticed that there was no apple sawfly at all in Per Christer Odén's orchard which was just planted on May, 2010. Only few trap catches were obtained in other orchards like Grönsaker Direkt, Helenelust and Kiviks Musteri. Kiviks Musteri is an exception. Although being an old orchard, it did not have so many trap catches. It could be because some area of orchard is IPM grown and the rest is organic. There was higher infestation in two older organic orchards, one from Sweden and another from Denmark. Both of these orchards are not part of the participatory research group.

Labor peak is a time period during a grower needs more labor than other time for doing his farming activities. Organic apple growing is not only the growers do in their daily life. Most of the growers produce other crops as well and they work themselves in the orchard or in the field. For most growers, labor peak occurs during April to June. This coincides with the monitoring time of the apple sawfly traps. When there is labor peak during the field season, it might become hard for them to monitor and change traps.

The growers are interested in continuing the work with the traps but buying readymade traps. Using readymade traps will save their time which they can utilize on other activities in the farm. They will monitor the apple sawfly and change the traps twice a week over a four week period during the 2012 season. They will send the traps to the researcher from the participatory group. The growers will also keep track of the phenological stages in their respective varieties and other biological data including weather. They wished to continue work with monitoring and changing traps every day. They feel that if a good model is developed for the apple sawfly, the model can be used for the forecasting by the advisors from Äppelriket and the Swedish board of agriculture (SJV) in the future. They reckon that it might be too much for some growers to follow the forecasting for many different insects. They believe it should be performed by an advisory service. They are still interested in the phenological stages because they learn a lot from that and some of the Biofix (starting date for day degree calculation) are based on phenological stage in combination with day degrees.

Out of 5 growers within the group, only 3 applied Quassia extract in their apple orchards. The growers knew that Quassia extract can be used against the apple sawfly in the meeting of the participatory research group. They got all relevant information about Quassia extract preparation from Per Juhlin (former advisor from Äppelriket) who is also selling wood chips of Quassia. The growers followed a common method of extract preparation soaking wood chips in hot water around 60°C for 24 hours. The extract was made a day before applying it. They said it worked pretty well against the sawfly. However, they believe that the result would be better if they have sprayed at right time. Two growers Per Christer Odén and Anders Månsson used Quassia extract against aphids also but they think that may be because of timing, it did not give good results.

Anders Månsson from Tomelilla has a future plan of setting up a modern storage chamber for increasing storability of his apples for longer period. Henrik Stridh, advisor from Äppelriket, is thinking to create a new brand of organic apples, for example, bio grown apples in Kivik. Growers from Kivik and Karlskrona have decided to expand their orchard area in the coming years. Per Christer Odén from Kivik has already ordered apple plants from Belgium for next three years (2012, 2013 & 2014). He mentioned that there is a high demand of locally grown organic fruits in the market and organic apple growing is also becoming a good business in Sweden. Kalle Johansson from Karlskrona also agreed on the view. It is growing day by day whatever be the motivation of the growers whether it is orientation towards money or environmental consciousness. They think that they are getting good price for their organic apples and at the same time, it is also good from the environmental point of view. All the growers within the participatory group are affiliated with Äppelriket which is basically a marketing company also doing sorting, packing and provides machinery services to the nearby growers. Äppelriket also provides advisory services to the growers affiliated to them. Along with advisory service from Äppelriket, the growers said that they get technical advices from the board of agriculture as well.

All those future plans of these people (both grower and advisor) can be related to growing consumer's interest towards organic and locally grown fruits and its growing business in Sweden. These are the factors that motivate the existing organic growers to expand their production area. This will also encourage the new growers to start organic production in Sweden. If there will be more organic production of apples, this might also affect the apple sawfly situation. As organic apple orchards are more prone to damages by the apple sawfly, the situation could be devastating if control measures are not used efficiently.

4. Discussion

The day degree model proposed by Zijp and Bloomers proved to be effective in forecasting the first emergence and flight period of the apple sawfly. Based on the model, the first trap catch should be obtained at an accumulative value of 177±10 dd when day degrees were calculated from 15th March. Zijp and Bloomers (1997) mentioned that there would be minimum standard deviation from the temperature sums if 15th March is used as the first date for calculating day degrees. In an experimental orchard at the Garden laboratory, the average temperature sum was 186-191 day degrees when there was the first emergence of sawfly adult. In Dammstorp, the first trap catch was seen at a value of 185-192 day degrees. Both the trap catches might have probably exceeded the higher limit of range for the first trap catch (187 dd). According to the model, the traps should have been installed when the temperature sum reached 157 dd (Zijp & Bloomers, 1997) during the 27thof April in the Garden laboratory and the 26th of April in Dammstorp. Since the sticky traps were not available by that time, there was delay of 2 days in the Garden laboratory and 3 days in Dammstorp. Possibly the first flight of the apple sawfly was not caught due to this delay. Otherwise, the model would be even more correct.

Quassia extract was sprayed in the experimental orchard in the Garden laboratory when it exceeded 85 day degrees from the egg laying to cover a large number of newly hatched first instar larvae (Graf *et al*., 2002). The day degrees were calculated from just before the peak flight of the sawflies. The reason for this was to time the Quassia application just before the peak hatching of the eggs. Since most sawflies lay eggs during the first day of their flight (Graf *et al.,* 2001), the peak flight curve can be translated into peak egg laying curve. The reason for spraying just before the peak emergence of first instar larvae is that the Quassia would prove effective only if the first instar ingests the Quassia extracts before making the tunnel (Kienzle *et al*., 2004). Another reason is that Quassia degrades already within 4-6 days (Psota *et al*., 2010). The peak hatching occurs just for a few days and the application should be made just before peak hatching to target the majority of the sawflies. That is why; effective management of the apple sawfly can be obtained if there is proper timing of application.

The results presented above show that Quassia extract is significantly effective against the apple sawfly (*Hoplocampa testudinea*). Apart from testing the efficacy of Quassia, the main aim of the experiment was to determine the precise timing for Quassia application. Miles (1932) reported that the timing of application of insecticide is very important for controlling the apple sawfly. Höhn *et al* (1993) also agreed that the timing is very crucial as the control measure is directed at the first instar larvae. Although day degree treatments seemed to be slightly better than petal fall stage, there was no significant difference between these treatments. The figures posed show that there was less infestation percentage for the day degree treatments than the petal fall stage treatment. Quassia extract was applied in the evening on the 21st of May for day degree treatment and it started raining in the morning on the 22nd of May. Therefore, it can be assumed that rain might have washed away some residual effect of Quassia extract. This explains that the day degree treatments could have been much better if there had been no rain after spraying.

For primary damage, the treatments were significantly different to control while for secondary damage, there was no difference between the treatments. There was heavy infestation of aphids in the experimental orchard. The control was more heavily infested than the treatments. It is accepted that it might have some relation with insignificant damage of the apple sawfly although we do not have biological explanation for that. The fruits were completely distorted and small. Leaves became curled and shoot growth was stunted. Quassia seemed to be efficient against aphids since there was not much infestation compared to control.

Fig. 14 Aphids and infested leaves (Photo: Dipesh Neupane)

It is common to spray during the petal fall stage. However, the petal fall stage has not been defined properly. Since petal fall occurs during several days, it is unclear at what point during petal fall, the application should be performed. In Dammstorp, the petal fall started on the 11th of May and after 6 days; there were almost no petals on the flower clusters. The petal fall began on the 12th May and almost lasted for six to seven days in the Garden laboratory. Due to unfavorable weather conditions, Quassia application was delayed until the 19th of May. This was a few days after the end of petal fall in Dammstorp and it was just at the end of petal fall in the Garden lab. The application according to the day degree model was performed on the 21st of May. Hence, the time difference between the two applications was small.

When the results were discussed with the participatory research group, it was said that these results could imply the exact timing of the application perhaps was not that important. Since the application at the end of petal fall in Discovery (Garden lab) and a few days after petal fall in Rubinola (Dammstorps Handelsträdgård by Jörgen Nilsson, the grower himself) gave similar results to the day degree application in Discovery (Garden laboratory) which was two days later. However, it was noticed that the result might have differed if the application at Dammstorp had occurred three days earlier at the end of petal fall. The group also considered the possibility of the petal fall occurring rapidly some years due to strong wind or rain while the sawfly egg hatching is controlled by the temperature sum. Hence, using petal fall as an indicator could prove to be successful in some years and in other years, it might not be the same. The timing of petal fall may also vary with apple varieties and some varieties may correspond better than others to the day degree model.

The group agreed that the day degree model is a more precise and manageable tool. However, they said that it requires more work with trap catches and it depends on reliable information about temperature sum, safe internet access and a working homepage where the temperature sums are stated. Using petal fall as an indicator could be simpler but requires more research during different weather conditions, in different varieties and at different points during the petal fall before its efficiency can be compared to that of temperature sum.

Within the participatory research group, Jörgen's apple orchard in Dammstorps Handelsträdgård is an orchard with relatively more infestation compared to other orchards. A monitoring method with white sticky traps showed that the number of the sawflies caught exceeded the threshold of damage in Dammstorp. The threshold of damage is about 20-30 apple sawflies per trap (Graf e*t al*., 1996b; Andermatt Biocontrol, 2010). Only a few number of trap catches were obtained in other orchards. It might be because they are relatively newly planted apple trees and the pest have not had time to establish yet. It could also be because there are no other apple growers nearby or infested old apple trees in the private home garden in the locality. In those orchards near to the sea, there was also few trap catches, may be because of high speed wind blowing from the sea towards the orchard area. It was observed in Dammstorp that traps just behind the greenhouse had comparatively more sawfly catches than those which were installed in an open space. Wind might also have some effect on the flight of the apple sawfly.

Per Juhlin works for a company which buys wood chips of *Quassia amara* from a German company and sells it to organic growers in Sweden. Ocampo *et al* (2010) stated that a company from Germany bought 3 tons of Quassia wood in the year 2006. In Germany, there is preparation of standardized quassin content commercially which is very costly for growers' use (Psota *et al.*, 2010). Extract from Quassia wood chips could be a cheaper as well as effective alternative for organic apple growers against the apple sawfly. Another reason could be that the growers are not permitted to use synthetic chemicals in organic production. In Conventional and IPM growing, the growers use synthetic insecticides like Mospillan 20 SP against sawfly which gives very good result (pers. comm. Stridh, 2011; Psota *et al*., 2010). This non standardized extract prepared from wood chips of *Quassia amara* could be a good choice to control the apple sawfly in organic orchards.

Even after the Quassia treatment, some larvae might survive from the effect since Quassia has a short residual period of about 4-6 days. The growers should check if there are any damages in the orchard. The growers need to examine for ribbon like scars or galleries on the small fruits (Kienzle *et al*., 2006b) after a few days of spraying. If the growers find damaged fruits, it is advised to thin or pick the infested apples and destroy them. By doing so, they will prevent further infestation leading to secondary damage of apple sawfly. There should be a regular monitoring and inspection of apple trees in the orchard. If the growers can control the damages caused by the apple sawfly, the yield of apples will not decrease and they can earn more profit from organic apples. Besides, using Quassia extract as a control measure against the apple sawfly, there are some other measures such as using parasitoids, fungi and entomogenous nematodes that the growers can apply in their orchard. The growers can plant flower strips in their orchards which will act as a habitat or source of food for natural enemies of the apple sawfly such as parasitoids. For this, further research on developing other control measures against the apple sawfly should be done to be used along with Quassia extract application. It is observed from the graph (Fig. 9 & 10) that there might be some competition which is reflected by the decline in number of trap catches during the full blooming period of the apple varieties. The observed decline in the trap catches during the full bloom could perhaps be artefact instead of which there could be only one peak if there is a competition between them. Future research should also focus on the competition between the full blooming flowers and the traps for attracting the sawfly adults.

5. Conclusion

Quassia extract is proved to be effective against the apple sawfly *Hoplocampa testudinea* in organic apple orchards. More appropriate time would be to apply the extract according to the forecasting of day degree model. Further continuous research is needed to get more reliable results. Some more information is required about the impact of Quassia extract on the beneficial organisms. It is suggested that the Swedish board of agriculture should provide an easy access to the homepage where all necessary day degree calculations are made and which can be helpful for forecasting as well. The growers and advisor wished the provision of advisory service for forecasting the apple sawfly by the Swedish board of agriculture.

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7. Appendices

7.1 Appendix I - Seasonal calendar of the participating farms.

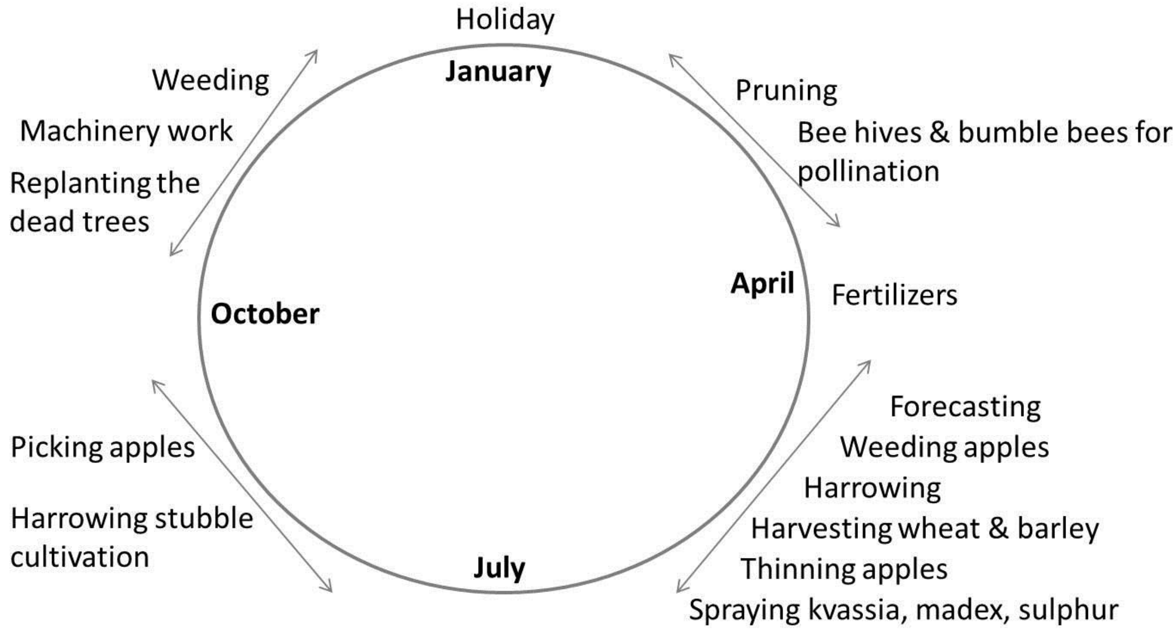

Fig. 12 Seasonal calendar (Helenelust)

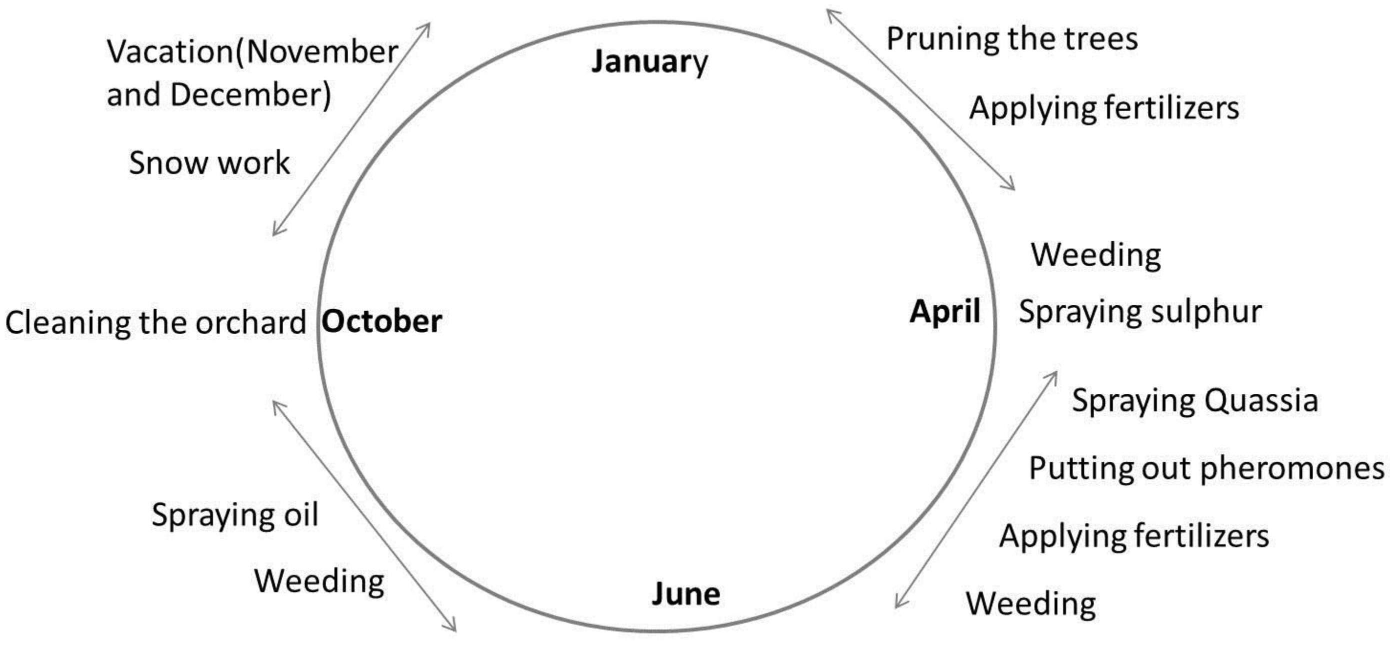

Fig. 13 Seasonal calendar (Dammstorps Handelsträdgård)

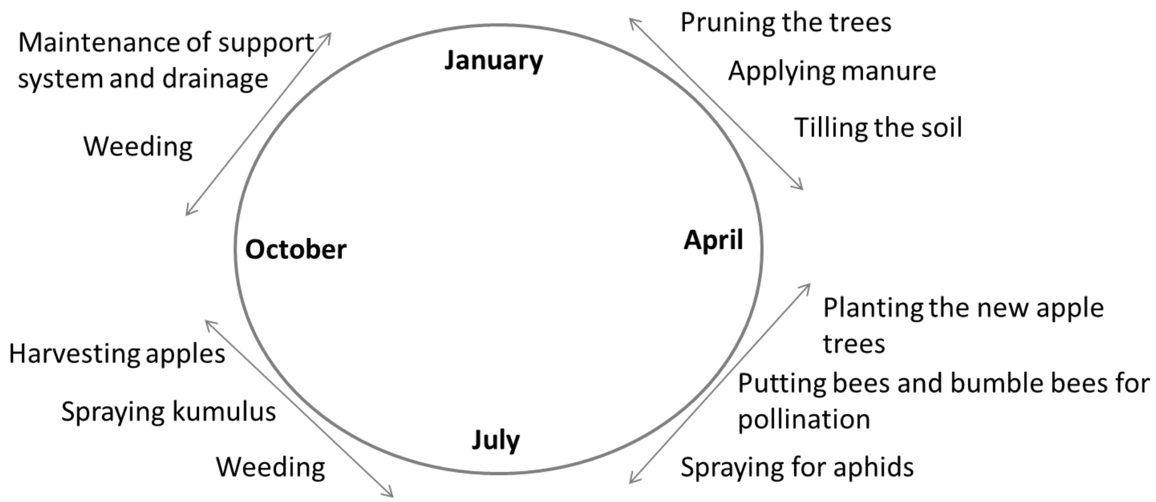

Fig. 14 Seasonal calendar (Per Christer Odén s farm)

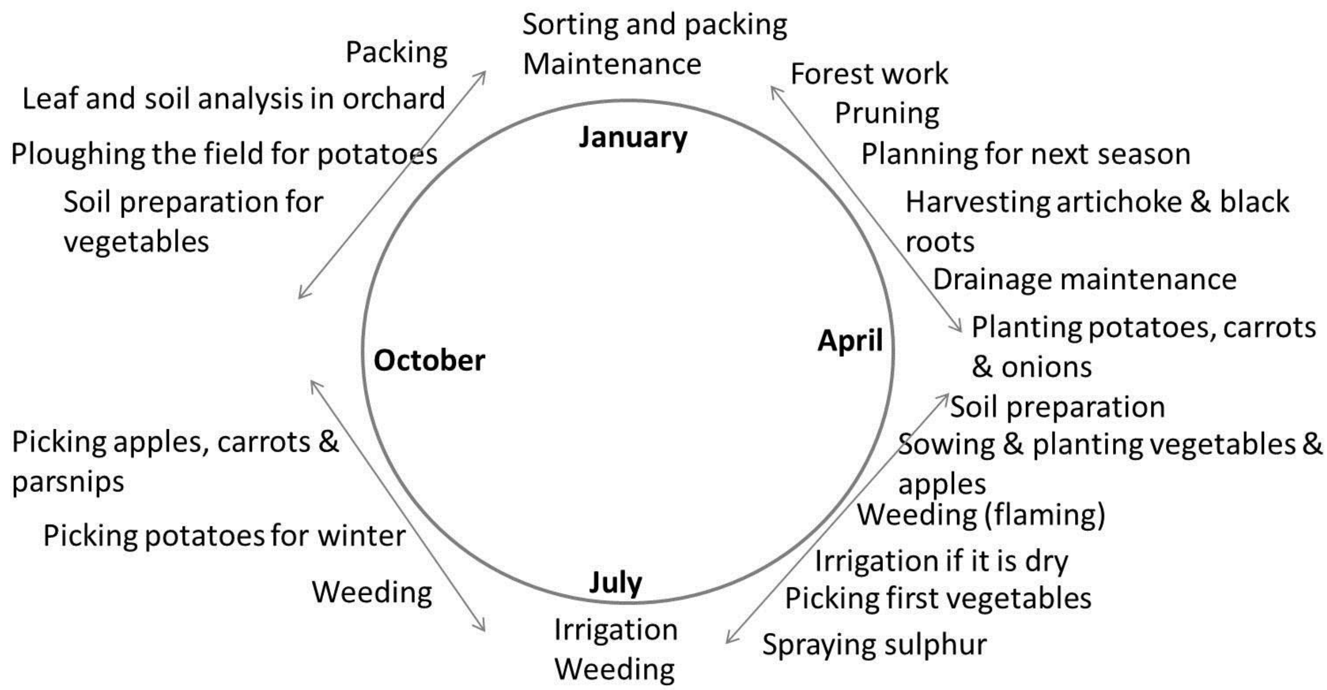

Fig. 15 Seasonal calendar (Grönsaker Direkt)

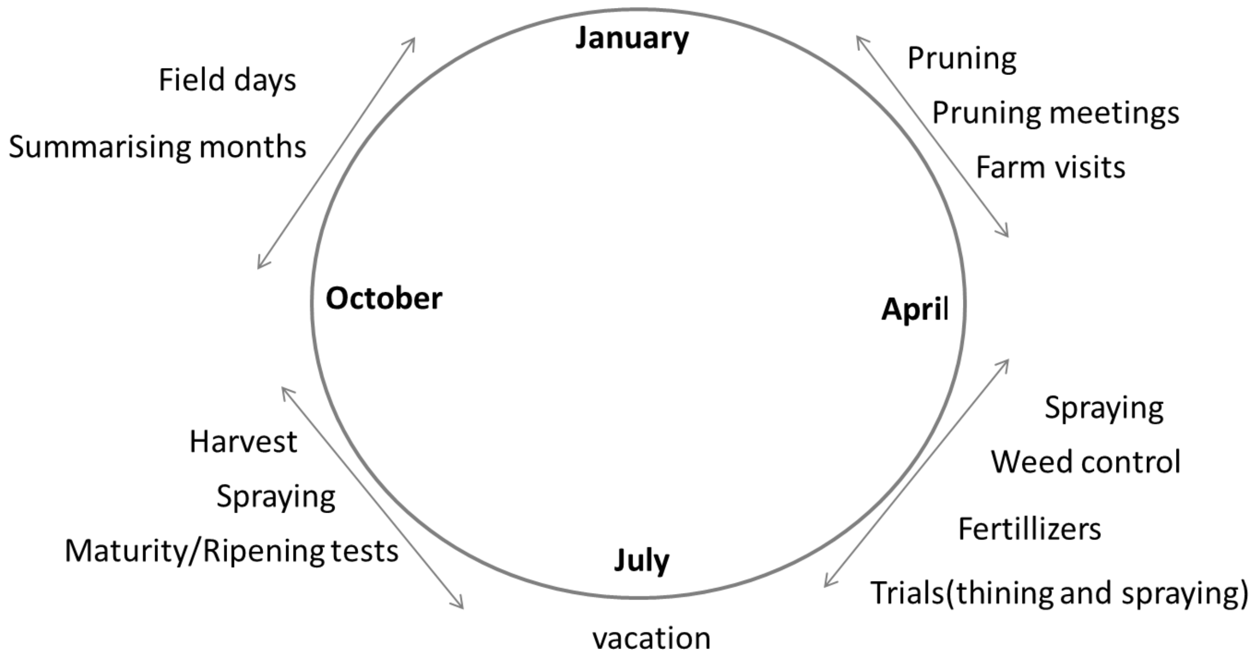

Fig. 16 Seasonal calendar (Kiviks Musteri)

7.2 Appendix II - Resource map of the participating farms

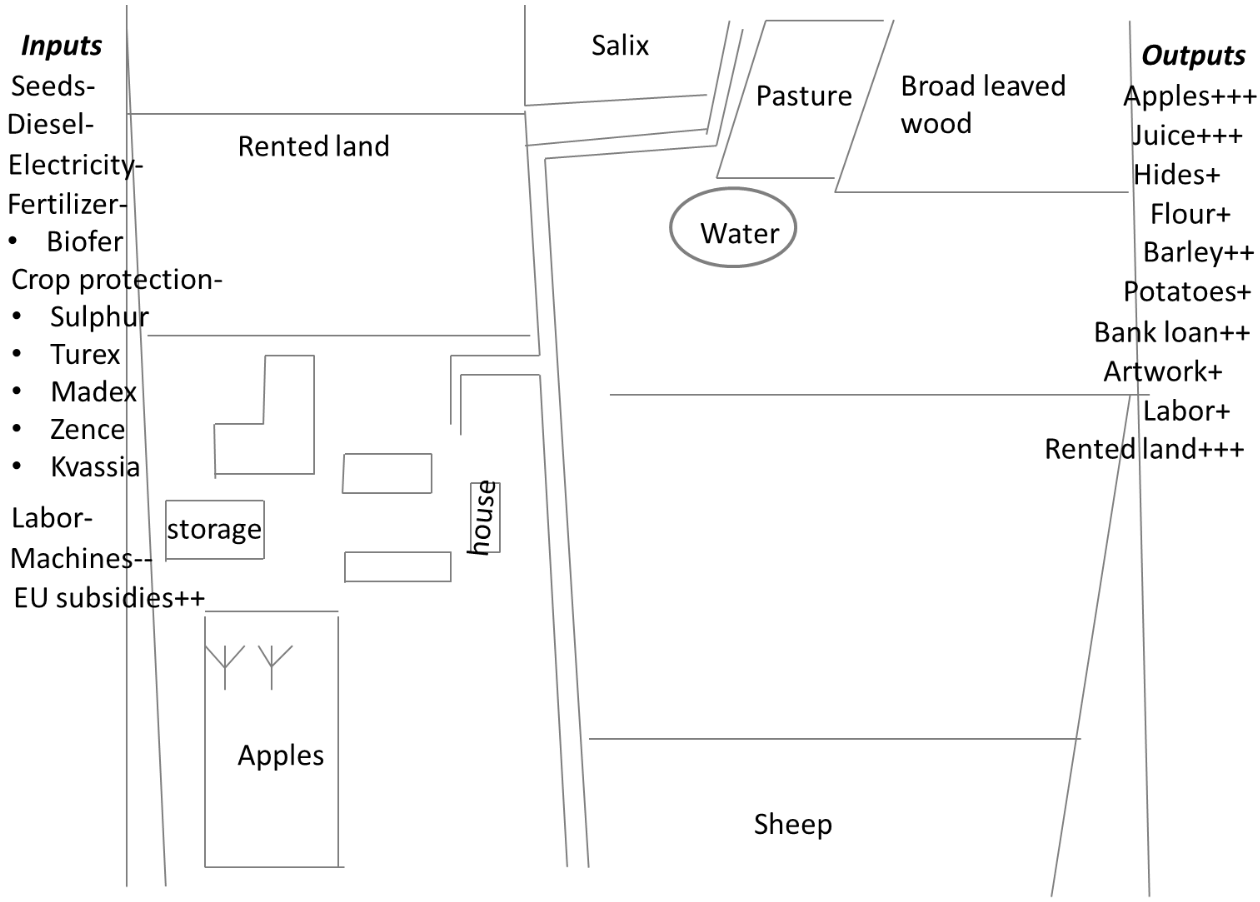

Fig 17. Resource map (Helenelust)

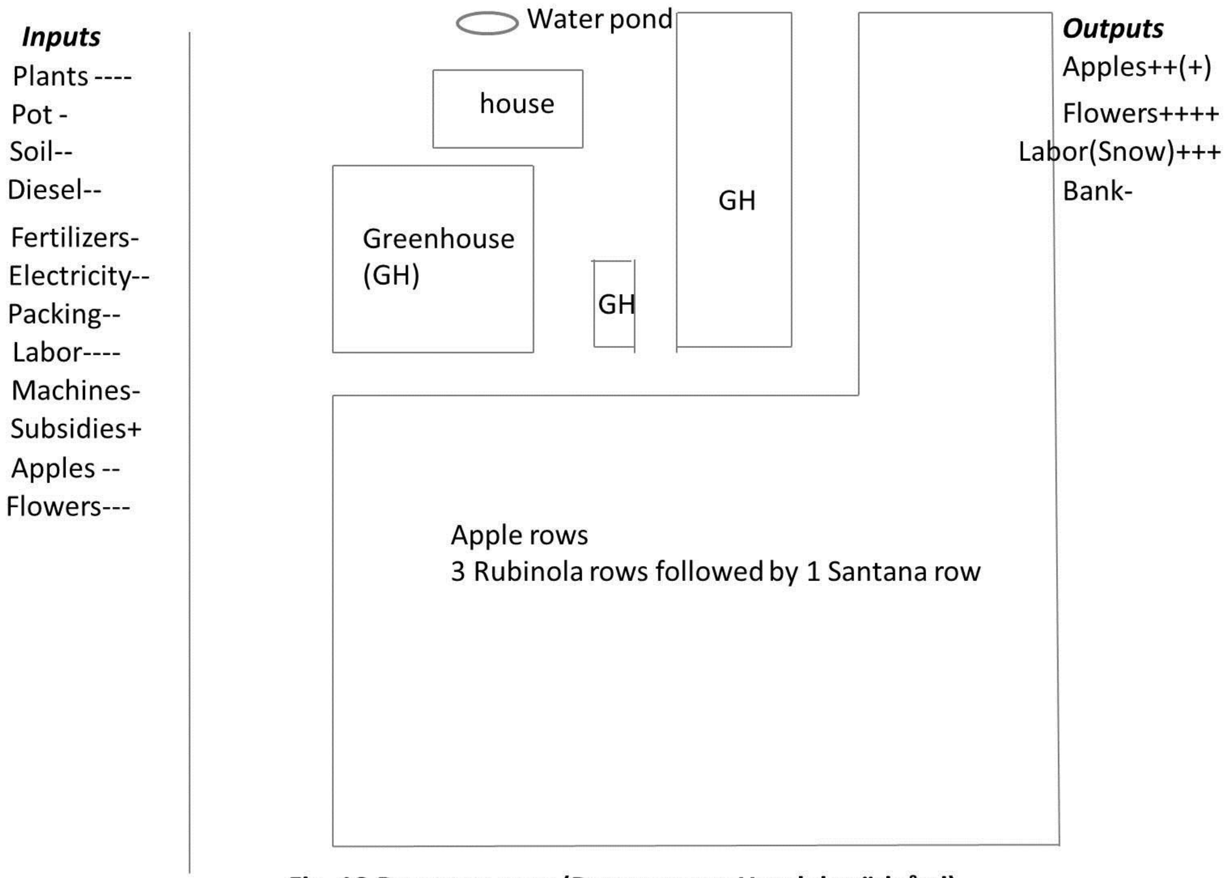

Fig. 18 Resource map (Dammstorps Handelsträdgård)

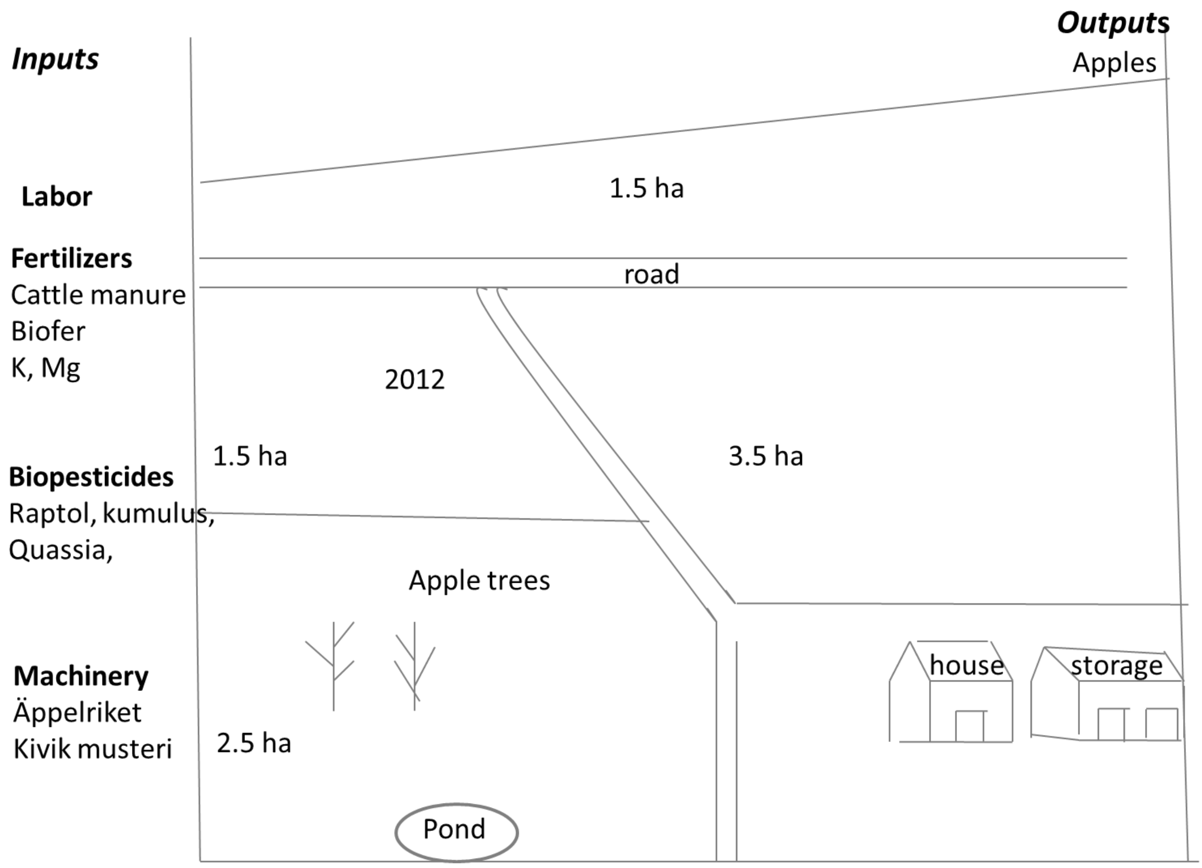

Fig. 19 Resource map (Per Christer Odén 's farm)

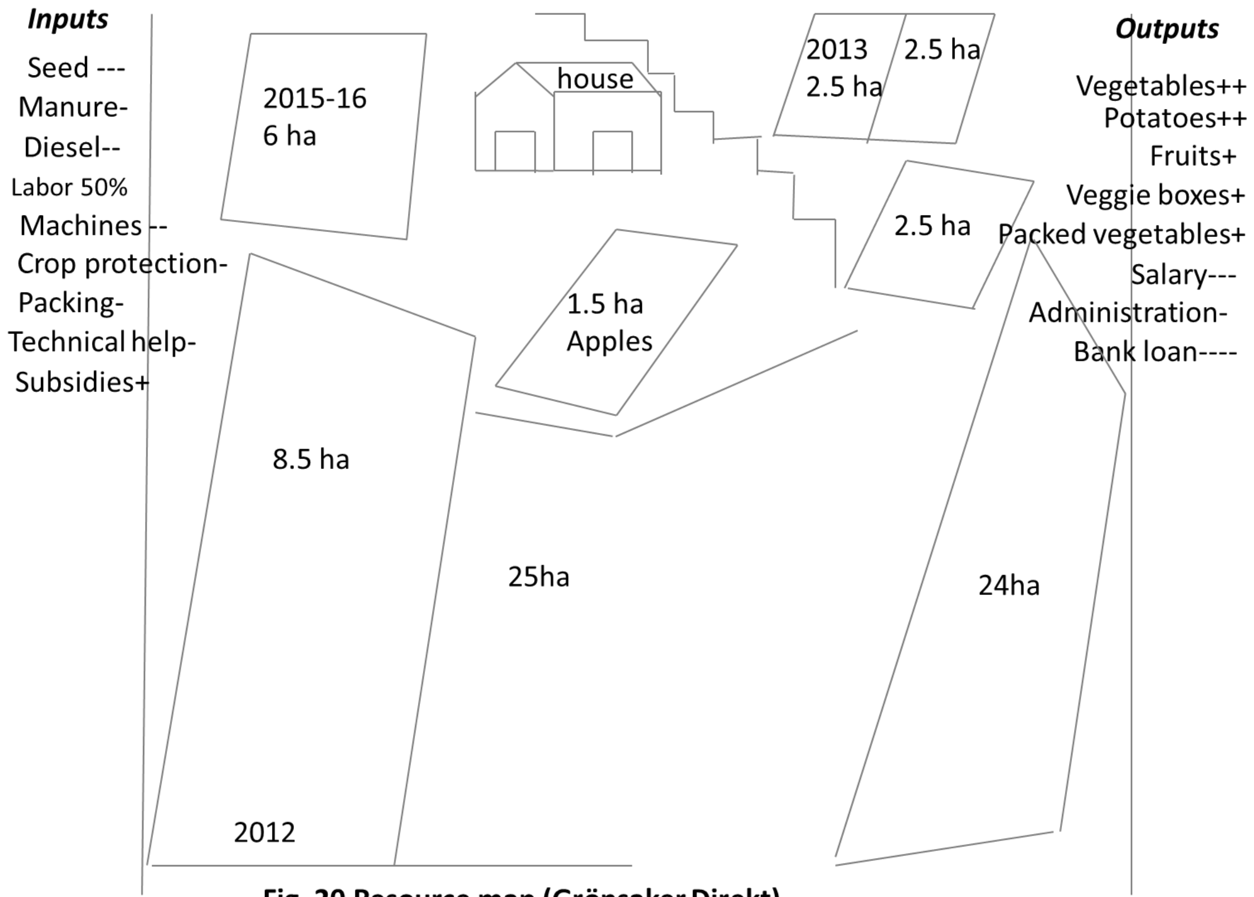

Fig. 20 Resource map (Grönsaker Direkt)

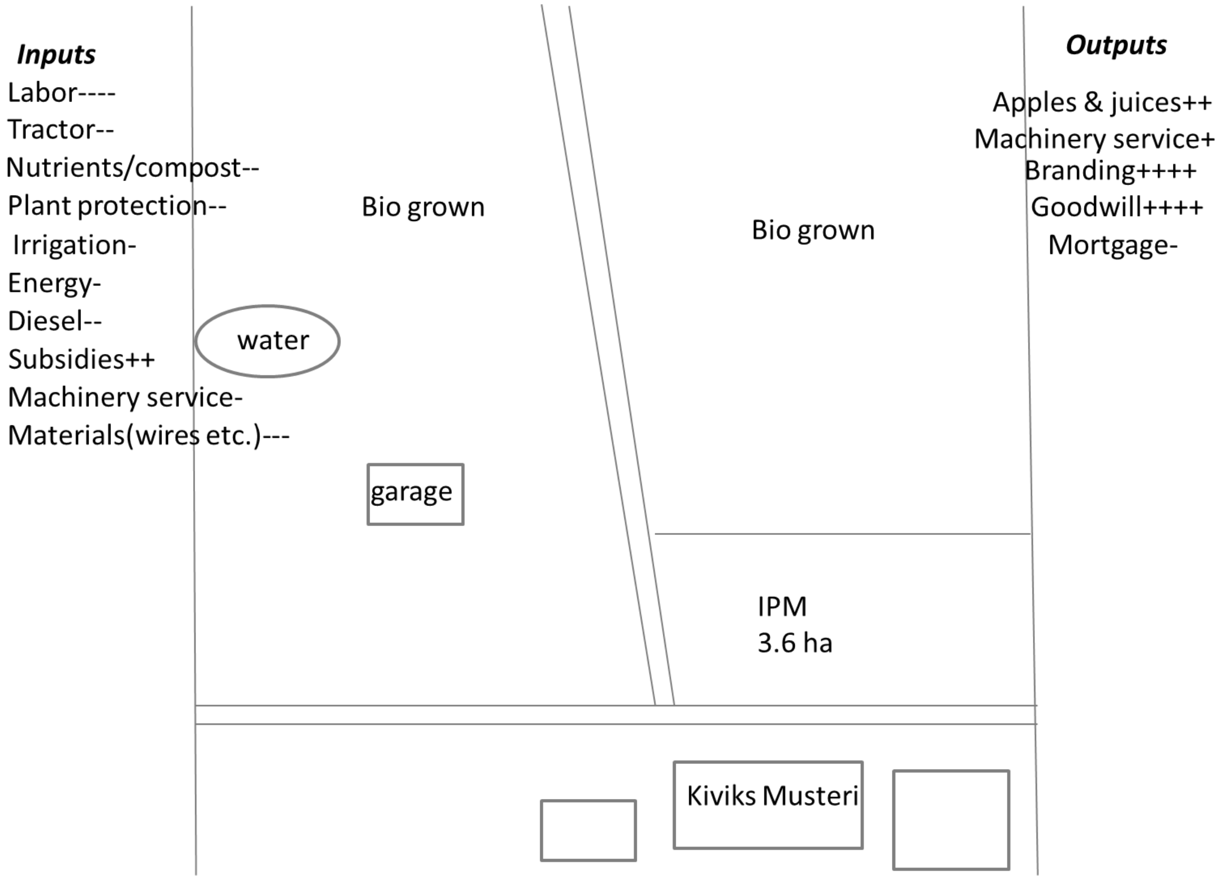

Fig. 16 Resource map (Kiviks Musteri)

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Plus sign (+) represents profit while Minus sign (-) represents cost for the farm. Four plus and minus signs are given for maximum profit and cost respectively while only one pus and minus is given for minimum profit and cost for the farm. There is an exemption for Per Christer Odén's orchard because there has been no harvesting commercially (estd. May 2010).