The strawberry blossom weevil

(*Anthonomus rubi* Herbst, Col.: Curculionidae)

– biology and effect on the yield

Jordbærsnutebille (*Anthonomus rubi* Herbst, Col.: Curculionidae)

– biologi og betydning for avlingen.

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Cand. scient. thesis 2001

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Front page photo: T. Kvamme.

Preface

This Cand. scient thesis is written at the department of Biology and Nature Conservation, Agricultural University of Norway. My supervisors have been E. Hågvar (IBN) and N. Trandem (Planteforsk).

I thank N. Trandem and E. Hågvar for excellent supervision during the study, and the staff at Planteforsk Kise and S. Kråkevik for equipment and practical assistance when the plots were laid out. I am grateful to the farmers who kindly let me do registrations in their strawberry fields, and A. Sønsteby for getting me in contact with the farmers. I also wish to thank T. Våge for advice when planning this study, F. Måge and J. Aasen for comments on the manuscript, A. Nes for answering my e-mails, my mother (M. Aasen) for comments on the English, A. Aastvedt for statistical assistance and T. Kvamme (Skogforsk) for help with taking photos, and identification of weevils. Furthermore, I thank K. Hovland for lending me her little Suzuki, and I appreciated living at the Sørbu's during the fieldwork. At last I will thank family and friends both for comment and discussions during the writing process and for helping me to relax in between the writing, and my partner Olav for support during the whole period.

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Ås, November 2001

Solveig Aasen

Som første avis i Skandinavia kan vi i dag bringe et bilde av den toscanske snutebillen, «Dracula Orientalis», som hadde tilholdsted i Arve Tellefsens berømte fiolin. (Snutebillen er sterkt forstørret.)

En annen snutebille hentet fra 'Flåklypa tidene', av Kjell Aukrust

1. Abstract

The strawberry blossom weevil (*Anthonomus rubi* Herbst) is a considerable pest of strawberries in Norway. The main objective of this thesis was to investigate the biology of *A. rubi* and see how *A. rubi* and insecticides influences the yield. Fieldwork was conducted in the south-east of Norway, in nine conventional and two ecological strawberry fields with 'Korona' (the summers of 2000 and 2001). Severed buds, adult *A. rubi* (by beating), number of flower trusses and the yield were registered. Registrations were done in the edge and middle of fields and in sprayed and unsprayed plots. Furthermore, the number of eggs in severed buds has been counted.

The number of *A. rubi*, severed buds and the yield varied considerably between the growers. Most weevils were found in the edge plots. There were more weevils in older fields, but also between fields of the same age, differences were found. The organic fields did not differ from the conventional fields in either number of weevils and severed buds or distribution of damage. Generally severed buds contained one egg of *A. rubi,* but in a relatively high amount (21%), there were two or more eggs. The distribution of eggs in severed buds was shown to change over time, but spraying did not influence the number of eggs per bud. A high correlation between the total number of severed buds and the total number of *A. rubi* was discovered. However, the number of *A. rubi* found early in the season cannot be used to predict the reduction in yield alone. Neither can the current threshold for spraying (10 severed buds/ 40 m. plant row, before flowering) be employed to forecast yield loss in the cultivar 'Korona'. The relationship between severed buds counted early in the season and the yield was actually positive in third year fields: The higher number of severed buds, the higher yield. The yield per flower truss decreased with increased weevil activity. This yield reduction was less in third year fields. Hence, older plants might have the ability compensate for the damaged buds. As no unambiguous relationships between the weevil activity and saleable yield per plant were found, the number of flower trusses was probably more important for the yield than the weevil, and explained over 70% of the variation in yield in first year fields. Insecticide applications were shown reduce the number of weevils and severed buds and increase the yield, especially in third year fields. In first year fields it might be better to spend money and time on improving the plant quality, than on insecticides. More work has to be done to develop alternative control methods. In addition, research has to be done to see if 'Korona' is able to compensate for the severed buds, and a new action threshold has to be developed. Furthermore, knowledge about the biology of *A. rubi,* such as; dispersal, hibernation sites, and dependence of different edge vegetation will be useful when new control methods are developed, and might explain why weevils are more abundant in some fields than in others.

2. Sammendrag

Jordbærsnutebillen (*Anthonomus rubi* Herbst) er et vanlig skadedyr i norske jordbæråkrer som gjør skade ved å bite av blomsterknopper ved egglegging. Feltarbeid ble utført i konvensjonelle og økologiske åkrer i sørøst Norge, somrene 2000 og 2001. Avbitte knopper, voksne *A. rubi* (ved banking) og avling ble registrert. Registreringer ble gjort i kanten og midten av åkrene, og i sprøytet og usprøytete forsøksruter. I tillegg ble antall egg i avbitte knopper registrert.

Det ble funnet en høy sammenheng mellom det totale antallet *A. rubi* funnet ved banking (dvs. riste plantene over et fat) og det totale antallet avbitte knopper; flere *A. rubi* ga som forventet flere avbitte knopper. Antall biller som blir funnet tidlig i sesongen gir alene ikke noe bilde på hvor stort avlingstapet blir. Heller ikke bruk av dagens skadeterskel (10 avbitte knopper per. 40 m. planterad før blomstring) i 'Korona' er til noen hjelp. Forholdet mellom avbitte knopper før blomstring og salgbar avling i tredjeårs felt var faktisk positivt; flere avbitte knopper ga høyere avling. Avlingen per blomsterstand reduseres med økt billeaktivitet. Reduksjonen er størst i førsteårs felt, noe som tyder på at tredjeårs planter har større evne til å kompensere. Derimot ble det ikke funnet noen tydelig sammenheng mellom billeaktiviteten (*A. Rubi* eller avbitte knopper) og avlingen per plante. Antall blomsterstander har trolig en større betydning for avlingen enn snutebillen: I førsteårs feltene forklarte variasjon i antall blomsterstander over 70% av variasjonen i salgbar avling.

Sprøytingen førte til en statistisk sikker reduksjon av antall snutebiller og avbitte knopper og en økning av salgbar avling. Størst effekt av sprøytingen ble funnet i tredjeårs felt, i førsteårs felt kan det heller lønne seg å bruke tid og penger på å bedre plantekvaliteten. I åkrer av samme alder, var det ingen tendens til at insekticidene påvirket fordelingen av bær i de ulike avlingskategoriene eller høstetidspunktet.

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Bruk av insekticider er per i dag eneste effektive måte å kontrollere billen på. Flere undersøkelser må gjøres for å utvikle alternative kontrollmetoder. Dette er særlig viktig med tanke på økologisk produksjon, der jordbærsnutebillen er et av de viktigste plantevernsproblemene. Videre forskning på feromonfeller og sorter som tåler eller unngår angrep, vil trolig være viktig i fremtiden. I tillegg vil grundigere kjennskap til biologien til *A. rubi* være viktig: Mer kunnskap om overvintringssteder, avhengighet av ulik kantvegetasjon og spredningsevne, vil være nyttig i utvikling av alternative kontrollmetoder. Disse faktorene kan kanskje forklare hvorfor noen åkrer har atskillige flere *A. rubi* og avbitte knopper enn andre.

1. Abstract

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3. Introduction

The strawberry blossom weevil (*Anthonomus rubi*) is a well-known pest in Norwegian strawberry fields, and it affects the yield by severing the flower buds. *A. rubi* causes most damage in the south-east of Norway (Stenseth 1970, S. Kråkevik pers. comm.), but it also occurs in the west of Norway and in Trøndelag. In the south of Norway *A. rubi* is seldom a problem (Henriksen 2001).

Strawberry (*Fragaria* x *ananassa* Duch) is a perennial culture. The number of flowers and flower stalks (Figure 1) increases from year to year, while the berries get smaller with age (Brandstveit 1978a and b, Meland 1985). The size of the berries also varies with their position in the inflorecence (Figure 1). The berries from the primary buds are the biggest, while the size of the secondary, tertiary and quaternary berries are much smaller (Måge 1998, Naumann et al. 1972, Eggum 2000). This is because the number of achenes (Figure 2), which determines the potential size of the berry, is reduced with increasing bud order (Eggum 2000).

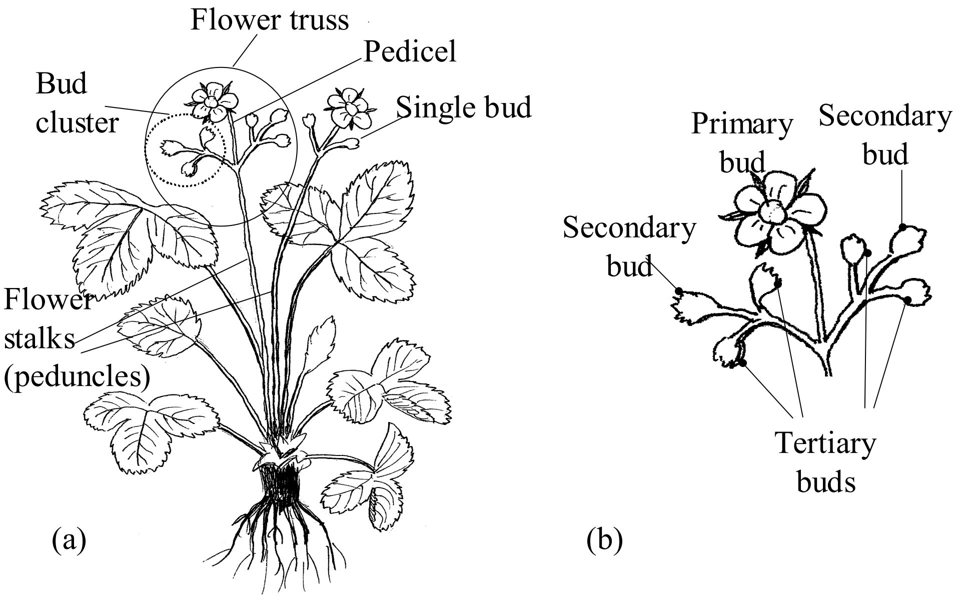


Figure 1: a) A strawberry plant, b) the different position of primary, secondary and tertiary buds in a strawberry truss.

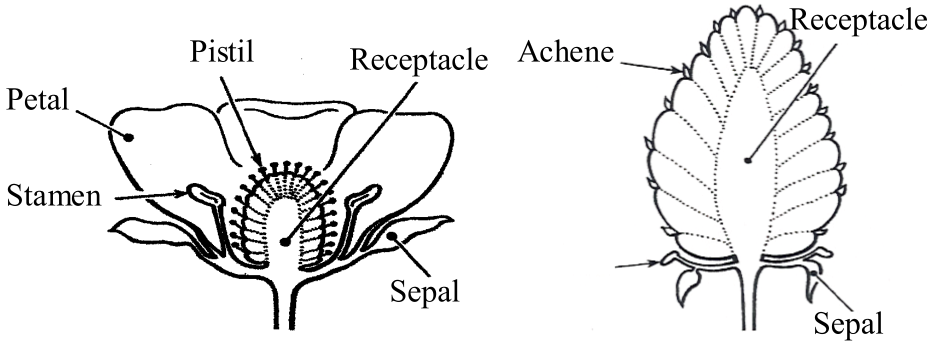


Figure 2: Schematic figure of a strawberry flower (left) and a fruit of strawberry (right) (Strand 1994).

In 1999 there were about 1280 growers cultivating 1600 ha of strawberry in Norway. Nearly all the production was outdoors, and less than 1% of the total production was organic. 'Korona' is the main cultivar (Anon. 2000). This cultivar has a high number of flowers compared with other cultivars (Höhn & Neuweiler 1993).

3.1. Biology of *A. rubi*

The strawberry blossom weevil is a pest because it destroys the flower buds of strawberry as a part of its development. *A. rubi* develops on strawberry plants, but also raspberry (*Rubus idaeus*), blackberry (*Rubus fruticosus*) and other plants in the rose family are host plants of the strawberry blossom weevil (Alford 1984, Stenseth 1970).

Figure 3: Adult *A. rubi* (2-4 mm). (Photo N. Trandem.)

A. rubi is univoltine (Stenseth 1970). The adult *A. rubi* appears in the field in April-May (Stenseth 1970), when the temperature exceeds 13-15ºC (Leska 1965). The weevils then have a period of feeding before mating. First they feed on young strawberry leaves (Figure 4) and later on flower buds and pollen from open flowers when they are available. They feed by drilling small punctures through the leaves and stalks (petioles), the latter sometimes being completely severed (Jary 1932). After mating, the female makes punctures in unopened flower buds, where the eggs are laid. Normally one egg is deposited per bud (Jary 1932, Leska 1965), and only one weevil can develop from each bud (Lekic 1963). After the egg is laid, the female cuts off the corresponding stalk partly or completely, by making another puncture (Figure 4). This second puncture usually stops the development of the flower bud, and the bud withers either partly attached to the stalk or on the ground. The whole process of oviposition takes about 35 minutes (Jary 1932). In bright sunshine, *A. rubi* flies (Jary 1932). If the weevil is threatened, it falls to the ground and feigns death (thanatosis) (Jary 1931). Larvae of *A. rubi* have been observed in open flowers (Hellqvist & Winter 1992, Lindblom 1930, N. Trandem pers. comm.) so the stalk is not always bitten off after oviposition. The female's egg laying capacity depends on the quantity and quality of the nutrition available during her development (Lekic 1963), and the number of eggs varies from 30- 260 (Jary 1932, Lekic 1963, Popov 1996a, Simpson et al. 1997). The larvae (three instars; Jary 1932) and pupae develop inside the bud. In July–August the new adults emerge, but this generation does not cause any economical damage before next spring (Jary 1932, Stenseth 1970).

Figure 4: Feeding punctures on strawberry leaves (left); strawberry bud severed by female *A. rubi* (right).

The adult strawberry blossom weevils overwinters (Stenseth 1970), but where is uncertain. It has been claimed that *A. rubi* overwinters among grass (Lindblom 1930) and litter (Lindblom 1930, Stenseth 1991), in cracks in the bark of trees, in plant detritus, upper soil layer and cracks near the root of the plants (Leska 1965). Recent research has shown that some *A. rubi* also overwinter within the field (Svensson 1999). According to another investigation, no overwintering *A. rubi* was found in the crown of the plant, the soil around it, in grass tufts and straw, in the vicinity of the plants and outside the fields, while many *A. rubi* overwintered in dry curled leaves from boundary hedges (especially from hawthorn hedges) (Jary 1932). Since the hibernation sites of *A. rubi* are in or near the strawberry fields, it is expected to find more weevils in older strawberry fields than young ones.

A similar species, *Anthonomus signatus* (Say), occurs in North America, where it attacks strawberry and a variety of other plants in the same way as *A. rubi* in Europe (Jary 1932).

3.2. Current practice of *A. rubi* control

Strawberry is the field crop in Norway with the highest number of pesticide applications, and furthermore, a relatively high dosage is used. On average three insecticide-treatments are applied in strawberry every season (Sætre et al. 1999). In very infected fields, 2-3 insecticide treatments are normally applied against *A. rubi* in the spring. Thus, it is important to look at the potential to reduce the use of pesticides.

The present recommended action threshold is 10 severed flower buds per 40 meters plant row before flowering (Stenseth 1998). This is a relatively low threshold, which easily is exceeded in areas where *A. rubi* is present (N. Trandem pers. comm.) In practice this threshold is not much used, and growers in affected districts usually look for *A. rubi* and severed buds to time the spraying, not to see if the threshold is exceeded.

When estimating the threshold, it was assumed that the yield reduction was a direct function of the number of severed flower buds (i.e. number of severed buds x mean berry weight). However, plants might have the ability to compensate for the effects of herbivores (Trumble et al. 1993, Sadras 1995), and recent research has shown that strawberry plants indeed are capable of compensating when some flower buds are damaged (Swarts et al. 1989, Khanizadeh et al. 1992, Hohn and Neuweiler 1993, Terrettaz et al. 1995, Cross & Burgess 1998, Cross & Easterbrook 1998, English-Loeb et al. 1999, Pritts et al. 1999). If the increase in yield is less than the loss caused by severed buds it is called partial compensation; when the increase in yield equals the loss, it is called full compensation; and if the increase in yield is greater than the loss it is called over-compensation. Such compensatory responses sometimes involve a delay in fruit maturation (Brook et al. 1992a, Sadras 1995). A Norwegian investigation on the relationship between the number of severed buds and yield has been done in the cultivar 'Senga Sengana' (Stenseth, 1970), and the existing threshold is probably based on this investigation. In the study on 'Senga Sengana' there was a tendency that plants with destroyed buds developed larger berries, but the larger berries did not fully compensate for the yield reduction caused by the loss of flower buds. Present research from other countries has shown that other cultivars possess the ability to fully compensate. Large plants can compensate for loss of yield by producing more and/or bigger berries when buds are destroyed. Thus the existing threshold might be too low (Cross & Burgess 1998).

Another problem with the present action threshold is that the damage has already been done when the farmer finds the severed buds. It would probably be better to predict the number of severed buds by looking for the weevils earlier. A Finnish method, where the plants are shaken over a white beating tray, has been developed for monitoring pests in strawberries. This method can be used to estimate the amount of strawberry weevils, capsids *Lygus* spp. and some natural enemies (Tuovinen & Parikka 1997).

3.3. Effect of insecticides

It is important to know if the insecticides have a positive effect on the yield since they are applied frequently. A lot of experiments have been done to look at the effect of different insecticides, but most of these only investigate the effect of spraying on the number of severed buds (e.g. Stenseth 1970, Borg 1971, Labanowska 1991 & 1997, Labonowska & Gajek 1992, Blümel 1998, Haegmark 1980, Statens plantevern 1977-1992). The pesticides used against *A. rubi* are broad-spectrum organophosphates and pyrethroids which influence the whole strawberry fauna (Anon. 2001). Blümel (1998) showed that some new pesticides designed for integrated production did not sufficiently control the strawberry blossom weevil. For example Bt (*Bacillus thuringiensis*) did not significantly reduce the infestation level (a 16% reduction in infestation level 7 days after first application and 0% reduction 7 days after second application). In comparison the pyrethroid esphenvalerate (Sumi-Alpha) had good effect with 81% reduction in the damage, but it is a danger that resistance to this pesticide will or has already developed in the weevil (Blümel 1998).

If the strawberry plants compensate, the effect of insecticides on the yield will be lower than expected. Only a few experiments have examined the effect of pesticides on the yield and none of these were in the cultivar 'Korona', as far as I know. Swedish investigations on the cultivars 'Bounty' and 'Kent' showed no significant increase in the marketable yield by spraying with pyrethroids, even though the pyrethroids had an effect on the proportion of severed buds in the cultivar 'Bounty' (Svenson, 2000). An experiment in America on *A. signatus* (Mc Cue et al.1993), revealed no effect of the pesticides on the weight of marketable yield in a field in the first year of production (cultivar 'Redchief'). Mörner (1981) found a positive effect of the pyrethroid fenvalerate on the yield of the cultivar 'Senga Sengana'. Stenseth (1970) showed that 'Senga Sengana' probably has not got the ability to fully compensate. Thus, it is likely that spraying will lead to increased yield in this cultivar. More research on the effect of both *A. rubi* and insecticides in the cultivar 'Korona' (the main cultivar in Norway) is necessary.

3.4. Organic strawberry production

Each season there is a lot of negative attention in the media about high pesticide use and finds of pesticide residuals in strawberries. The authorities have introduced regulations that lead to withdrawal of pesticides and difficulties in registering new ones. In addition, resistance to registered pesticides is developing. The conventional farmers' problem is how to control pests without effective pesticides. In addition, more people are concerned about food safety and the effect of pesticides on the environment, and they are probably willing to pay a higher price for ecological strawberries. For these reasons integrated and organic strawberry production is of current interest.

Experience from organically grown strawberries in Sweden shows that *A. rubi* is the most serious pest, and there is no way of controlling it. The same is the case in the south-east of Norway (A. Sønsteby pers. comm.). Thus, we need to know more about *A. rubi*'s biology to be able to find alternative methods of controlling *A. rubi*.

3.5. The purpose of this study

The aspects of the biology of *A. rubi* investigated in this study were:

- How is the adult weevil distributed on three spatial scales: between fields, within a field and within a double row?
- How is the weevil's oviposition pattern?
- Where does the adult *A. rubi* overwinter?

In addition some applied aspects were studied:

- How does the strawberry blossom weevil affect the yield?
- How do pesticides influence this effect?
- How are the questions above influenced by the age of the field?
- Can the Finnish beating method be used to predict damage?
- Are there any differences in weevil activity between organic and conventional fields?

4. Methods

The main fieldwork was conducted in conventional and organic fields in the east of Norway, 2000. Additional registrations were done in the organic fields early spring and summer 2001. Registrations of *A. rubi*, severed buds and yield were done in different types of plots (see 4.1. Description of the layout). In addition, severed buds were examined to see how many eggs they contained, and spring litter samples were collected. Most of the registrations were done in the cultivar 'Korona'.

4.1. Description of the layout

Registrations were laid out in the fields of 5 conventional and 2 organic growers (Figure 5).

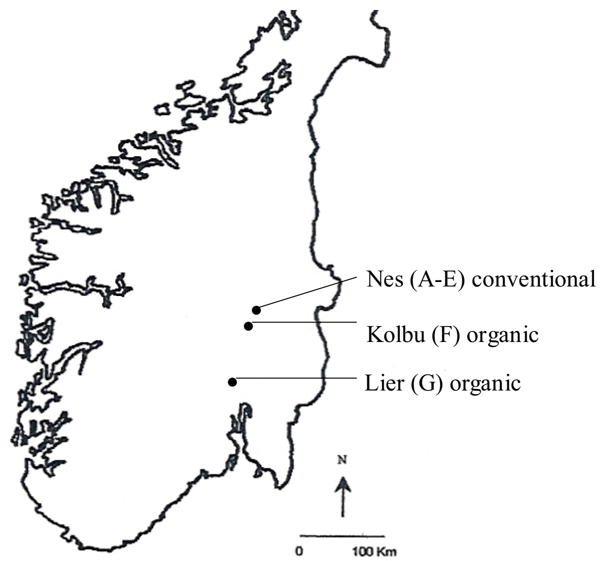


Figure 5: Location of the 7 different growers (A-G) in the south-eastern parts of Norway where the fieldwork was conducted.

4.1.1. Conventional fields

Nine conventional fields were included, all with 'Korona' and situated at Nes in Hedmark (Appendix 1). There was one field in its first year of production; called first year field, and one field in its third year of production (third year field) at grower A-D. At grower E, fieldwork was only carried out in a third year field.

The conventional growers used pesticides and artificial fertilisers. The plants were in double rows without plastic mulching. There were between 4300-5300 plants per daa (Table 2). A sprinkler was used to irrigate the plants, and the vegetation between the rows was removed by herbicides.

4.1.2. Organic fields

Fieldwork was conducted in two organic fields in different districts (Appendix 1). One first year field was situated at Kolbu in Oppland, grower F. This field was in its first year of production in 2000, but genetically the plants where 2 years old. At grower F, a few extra registrations where done in a field of cultivars (Figure 6). The other organic field was at Lier in Buskerud, grower G.

The organic growers did not apply any pesticides, and used only approved organic fertilisers. The plants were planted in double rows, mulched with plastic, and a trickle irrigation system was used. Between the rows, grass and clover that was mown about once a week grew. There were between 3300 and 5000 plants per daa (Table 2).

Row number:											
1	2	3	4	5	6	7	8	9	10	11	12
'Bounty'	‘Inga’(stam)	‘Oda’	‘Onebour Marmelada’	‘Rita’	‘Korona’	‘Karan’	‘Inga’ (elite)	'Bounty'	‘Inga’ (elite)	'Bounty'	'Bounty'
		S			S		S			S	
		B			B		B			B	

Figure 6: Map over organic field of cultivars at grower F. Plots where beating (B) and severed buds (S) registrations were done (cf. 4.2. Plot registrations). Each plot was 15 plants long and one double row wide. The 0,9 daa field was covered with agryl from 02.12.99 until 20.05.00. Row no. 1 bordered to a small road, some edge vegetation and trees, otherwise this field was surrounded by cereals and grass.

4.1.3. Description of the plots

In each conventional field (except grower E) four plots were laid out as shown in Figure 7. There were only two plots at grower E (Figure 8). Each plot was 15 plants long and two double rows wide, thus consisting of 60 plants (Figure 7).

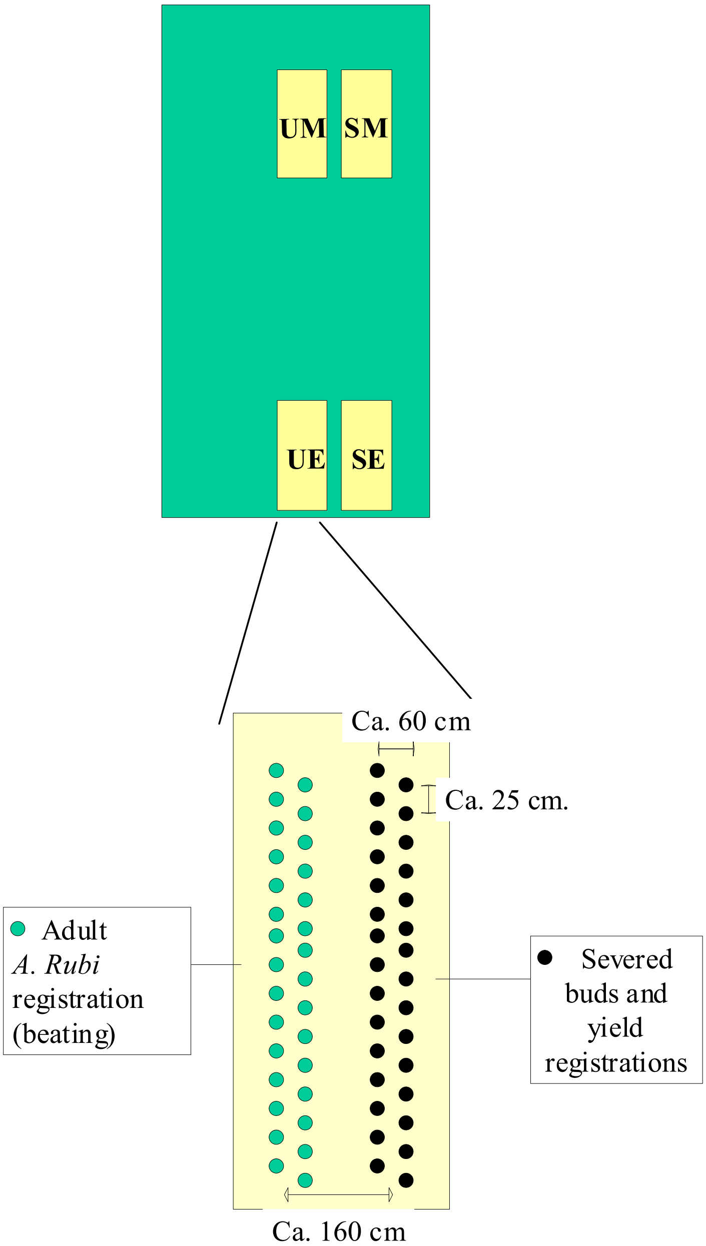
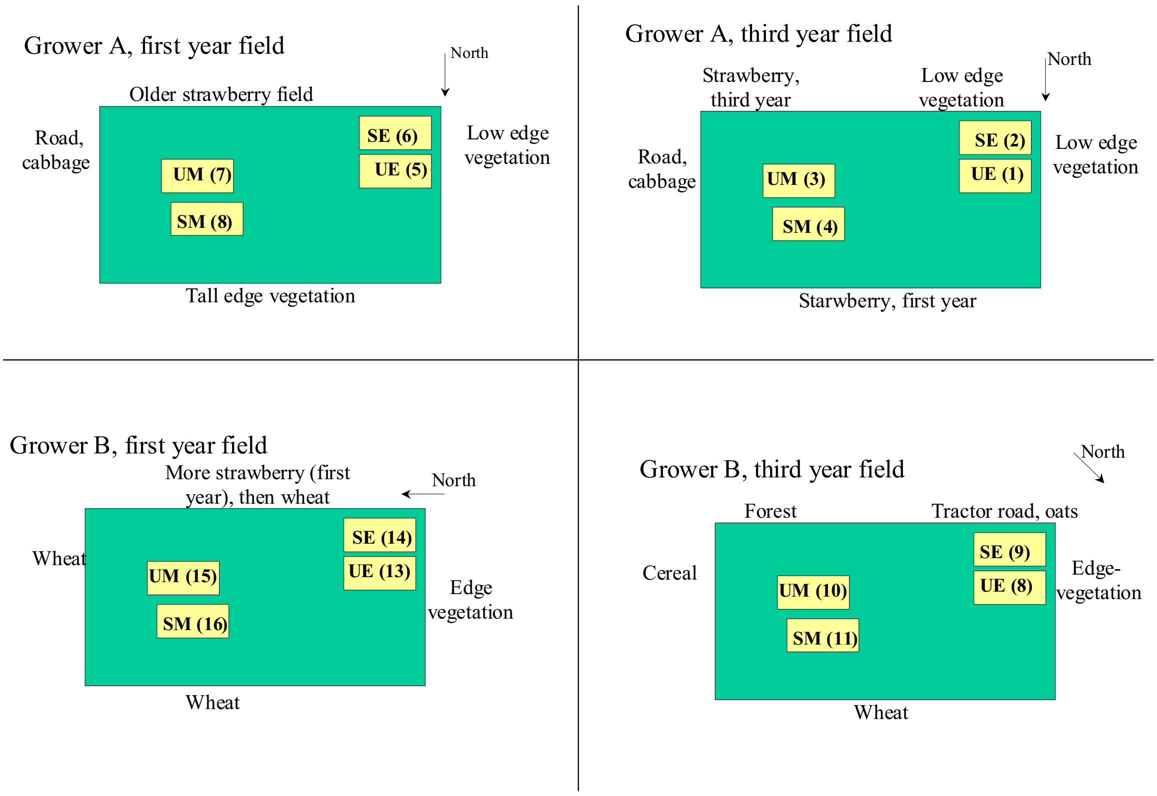


Figure 7: Plot layout at conventional farms. U: unsprayed, S: sprayed, E: edge and M: middle.

Edge vs. mid- field

In each field one half of the plots were usually placed mid field, and the other half near the edge (cf. Figure 8 and 9). An interior plot is defined as a plot with strawberry plants that is more than ten metres from normal edge vegetation like wild flowers, wild raspberries, bushes and trees, and more than ten metres from older strawberry fields. The edge is defined as a plot with strawberry plants 2 metres or less from edge vegetation and older strawberry fields. Because an edge plot is a plot close to places the weevil might overwinter, one would expect more weevils there than in interior plots. Figure 8 and 9 show the orientation, plot location and neighbouring vegetation of each conventional and organic field (see also Appendix 1 and 2). In the conventional fields, the grower applied insecticides, so both sprayed and unsprayed plots could be studied (see below).



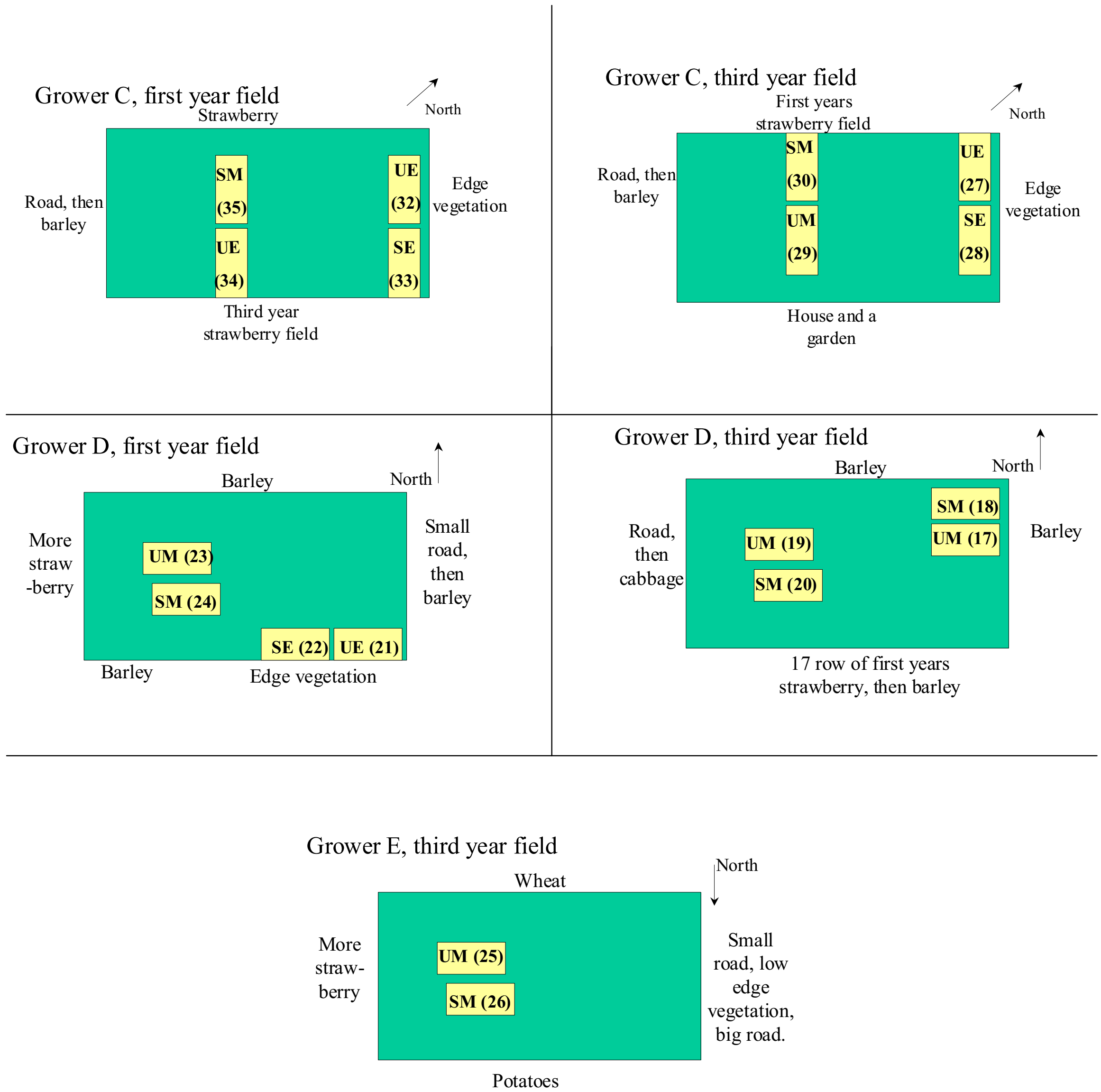


Figure 8: The conventional strawberry fields (A-E). Plots sprayed with insecticides against *A. rubi* (S), unsprayed (U), edge (E) and middle (M), Plot numbers (cf. Appendix 2 and 3),

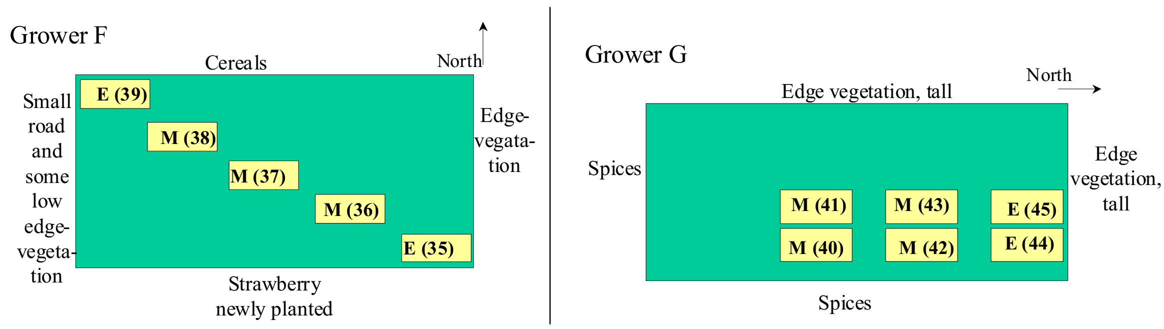


Figure 9: The organic strawberry fields (F-G). Plot numbers (cf .data in appendix) , edge (E) and middle (M).

Sprayed vs. unsprayed

Half of the plots were not sprayed with insecticides that are known to harm *A. rubi*. This was accomplished by marking the plot, and the grower stopped spraying when he approached the plot. The type of insecticide and date of spraying on the rest of the field was registered (Table 1). When the grower had mixed the insecticide with a fungicide, the plot was not sprayed with fungicides either. The insecticide data from grower D is lacking, but insecticides were used in his fields and the unsprayed plots were not sprayed.

Table 1: Overview of insecticides applied in the conventional fields (sprayed plots, 2000). Spraying data from grower D are not availeble.

Grower A	Grower B		Grower C		Grower E
First and third year fields:	First year field:	Third year field:	First year field:	Third year field:	Third year field:
13 May: Morestan 22 May: Morestan 25 May: Gusathion+Perfekthion 30 May: Sumi-Alpha 10 June: Gusathion+Perfekthion	26 May: Sumi-Alpha 2 June: Fastac	20 May: Gusathion 26 May: Sumi-Alpha	31 May: Gusathion 9 June: Gusathion	21 May: Roxion 21 May: Gusathion 24 May: Gusathion	25 May: Gusathion

Table 2: Overview over the fields and registrations year 2000 and 2001. 2001 registrations below the thick line.
Conv = conventional fields; Org = organic fields.
Date in ( ): when the severed buds were registrated seperately for each row in the double row.

Plot number:	Year of production:	Size in daa: [*]	Plants/ daa:	Farmer:	Location:	Farming-practices	Flowering had started:	Flower truss counting:	Weevil registration:	Severed bud registration:	Yield registration:	Nr of buds examined:	from unspra-yed plots	from spra-yed plots
1-4	1	6[12]	4300	A	Nes	Conv.	7.June	7.June	16.May-15.June	20.May-21.June (1.June)	14.July-11.Aug.			
5-8	3	6[12]	4300				1.June	7.June	16.May-15.June	20.May-21.June (1.June)	14.July-9.Aug.			
9-12	1	10[16]	4400	B			1.June	8.June	16.May-30.June	20.May-30.June (1.June)	14.July-7.Aug.			
13-16	3	14[10]	5300				20.May	8.June	16.May-30.June	20.May-30.June (1.June)	14.July-7.Aug.	65	31	34
17-20	1	8 [18]	5300	C			2.June	8.June	19.May-2.July	19.May-2.July (26.May)	3.July-4.Aug.			
21-24	3	10 [18]	5300				19.May	8.June	19.May-2.July	19.May-2.July (26.May)	3.July-4.Aug.	100	33	67
25-28	1	8	4500	D			2.June	9.June	16.May-25.June	19.May-25.June (26.May)	-	60	16	44
29-32	3	15	4500				22.May	9.June	16.May-25.June**	19.May-25.June (26.May)	-	95	38	57
33-34	3	50	4800	E			20.May	6.June	16.May-17.June	20.May-17.June (25.May)	-	38	23	15
35-39	1	3	3300	F	Kolbu	Org.	14.June	5.June	23.May-27.July***	23.May-27.July** (31.May)	25.July-10.Aug***	48	48	
40-45	1	3	5000	G	Lier		18.May	-	10.May-18.June	10.May-18.June (30.May)	-	68	68	
46-49	2	1	3300	F	Kolbu		23.May	-	23.May & 31.May	23.May & 31.May	-	-	-	-
35-39	1	3	3300	F	Kolbu	Org.	19.June	-	9.June-10.July	9.June-10.July	-	100		
40-45	1	3	5000	G	Lier		4.June	-	4.June-15.July	4.June-15.July	-	300		

* total size of strawberry field, if the actual field boardered to another strawberry field of another age class.Missing registration ** 2.June and *** 20.July.

4.2. Plot registrations

Table 2, Appendix 2 and Appendix 3 gives an overview of registrations done in the different fields year 2000 and 2001.

4.2.1. Weevil activity

The activity of the adult weevil was estimated in two different ways:

- By using a beating tray to estimate the number of adult *A. rubi.*
- By searching for severed buds (on the ground or still partly attached to the plant).

The weevil activity was registered in all the plots 2000. In 2001 registrations were done in the same plots as the previous year, but only in the organic fields.

Number of adult *A. rubi*

In each plot the number of adult *A. rubi* was counted approximately once a week in one of the double rows (i.e. 30 plants cf. Figure 7). The Finnish method was used (Tuovinen & Parikka 1997:) Each of the 30 plants was shaken over a white tray (40 cm in top diameter, 30 cm in bottom diameter) for about 3 seconds. The tray had a 120° sector cut off, so it could easily be placed under the leaves and flower stalks (Figure 10). After shaking, the weevils that dropped into the tray were counted, and thereafter put back on the plant.

Figure 10: The beating tray used in this study.

The counting was done in nice weather if possible, i.e. dry plants, sun and no wind. Table 3 shows weather and temperature when the beating was done.

Table 3: Temperature and weather data, when the beating was conducted, all the registration dates year 2000 and 2001. s: sun, (c): a few clouds, c: cloudy, r: rain, n: no wind, (b): a weak breeze, b: breeze, w: wind.

2000

Farm	1st sampling	2nd sampling	3rd sampling	4th sampling	5th sampling
A	16 May 22°C (c)b[!]	20 May 15°C sb	25 May 14°C s(b)	01 Jun 13°C s(b)	07 Jun 14°C cb
B	16 May 21°C (c)b[1]	20 May 15°C s(b)	25 May 15°C s(b)	01 Jun 14°C cw	07 Jun 14°C c(b)
C	16 May 22°C (c)b[1]	19 May 12°C cb[3]	26 May 12°C sb	02 Jun 14°C cw	08 Jun 18°C cb
D	16 May 19°C (c)b[1]	22 May 17°C s(b)	26 May 13°C cb	02 Jun 12°C rw[2]	09 Jun 15°C sb
E	16 May 19°C (c)b[1]	20 May 12°C s(b)	25 May 14°C (c)(b)	01 Jun 14°C sb	07 Jun 15°C cn
F	23 May 11°C (c)b	31 May 11°C cb	06 Jun 16°C (c)b	14 Jun 12°C cw	22 Jun 17°C (c)b
G	10 May 20°C (c)n[1]	18 May 15°C cb	23 May 16°C (c)b	30 May 13°C (c)b	05 Jun 15°C (c)n

2000 ctd.

Farm	6th sampling	7th sampling	8th sampling	9th sampling
A	15 Jun 17°C cb	21 Jun 17°C c(b)[3]		
B	16 Jun 13°C sb	23 Jun 15°C rw[2]	30 Jun 17°C cw	
C	16 Jun 14°C cb	24 Jun 17°C (c)n	02 Jul 17°C (c)n	
D	17 Jun 17°C (c)(b)	25 Jun 15°C (c)b		
E	17 Jun 16°C s(b)			
F	29 Jun 14°C cn	06 Jul 17°C cb	13 Jul 17°C c(b)[3]	27 Jul 19°C (c)(b)
G	11 Jun 14°C sb	18 Jun 16°C (c)(b)		

2001

Farm	1st sampling	2nd sampling	3rd sampling	4th sampling
F	9 Jun 14°C (c)(b)	19 Jun 19°C Sn	29 Jun 18°C (c)b	10 Jul 22°C (c)(b)
G	4 Jun 17°C s(b)	13 Jun 18°C Sb	24 Jun 25°C sn	5 Jul 26°C sb

[1] Beating only [2] Severed buds counting only [3] Wet plants.

Number of severed buds

After beating, the number of severed buds from the adjacent double row (30 plants) was counted (cf. Figure 7). Both the buds that had fallen to the ground and those still dangling on the plant were included. The buds were removed from the plot after counting, and some of them were examined to see how many eggs they contained (see 4.2.4). Parts of the season (see Table 2) the severed buds were registered separately for the left and right row in a double row. The rows were sorted according to which cardinal points they were facing. Those facing the sunniest direction (i.e. south, west or south-west) were placed in one group, and the other rows facing north, east or north-east in another group.

In the cultivar field at grower F the two registration methods had to be done in the same row (cf. Figure 6).

Sometimes whole clusters were severed by one puncture. A cluster is either a part of a flower truss or a whole flower truss depending on where the stalk has been punctured (see Figure 1). If a whole cluster was bitten off, this was registered as one bud. Thus the number of damaged buds was underestimated by about 2%, assuming the same proportion of clusters was bitten off in all the plots. No difference in the proportion of severed clusters was found between sprayed and unsprayed plots.

4.2.2. Yield registrations

The yield was registered in six fields (the fields of the conventional growers A, B and C). Registrations were done on the same plants as where the number of severed buds had been counted. The picking was done at the same frequency as the growers (three times a week), starting when the grower began to harvest, and continuing as long as he harvested. Yield registrations were also done in the organic field F, but only for the first three weeks of the harvesting season.

The berries were sorted into four different categories and weighed: 1) big (> 30 mm in diameter); 2) medium (25-30mm); 3) rotten (berries with sign of rot damage); and 4) non-marketable due to small size (<25mm) or other damage than rot.

4.2.3. Number of flower trusses

After the sampling had started it was realised that the number of flower trusses varied between plots, and that this probably would influence the result. In addition to the obvious fact that plants with more flowers have a higher yield potential, plants with many flower trusses may have a higher ability to compensate for damage caused by the strawberry blossom weevil. Research has shown that the yield reduction is greater on plants with few flowers (Cross & Burgess 1998). Thus, in the beginning of June the number of flower trusses (Figure 1) was counted once in one double row (e.g. 30 plants) in all the plots (see Table 2, and Appendix 1). The counting was done on the same plants as the severed buds and the yield were registered.

4.2.4. Number of eggs per bud

In the second half of May 2000, some of the severed buds were brought to the laboratory and dissected to see how many eggs they contained (if any). Some of these buds were from severed clusters. The buds were collected from different farms (both organic and conventional) and different types of plots (Table 2). The summer 2001 buds from the organic fields were examined (Table 2).

4.2.5. Spring litter samples

To look for overwintering *A. rubi,* samples of leaf litter were taken from grower G in the spring 2001 (29 April; Appendix 1). Eight samples were taken just outside the field and eight samples from within the field. Samples were taken by means of a circular frame, embracing an area of 0,125m^2. Half of the samples outside the field were taken from litter the grower had removed from the field in the autumn, and the other half from naturally occurring leaf litter. Within the field the samples were taken from the plots, where the grower had left the leaf litter. The litter was collected in plastic bags, transported to Ås and then put into emergence traps (photoeclectors; Figure 11).

Figure 11: One of the emergence traps used in this study.

The emergence trap was 0,125m^2 at the bottom. A hole in the top lead into a glass funnel with ethylene glycol, where emerging insects got trapped. The organisms that were found in the emergence trap were investigated in search for *A. rubi*. Candidates were examined to be sure they were not mistaken for *A. brunnipennis* (Runge 1991). Individuals of *A. rubi* were sexed by studying mesocoxae (hips of middle leg pair, Figure 12).

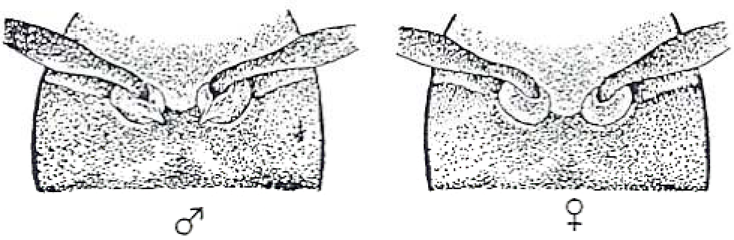


Figure 12: Mesocoxae of *A. rubi*: male- pointed (left) female- rounded (right) (Lekic 1963).

The results from the spring litter traps were used together with the results concerning the spatial distribution of *A. rubi* from field to field and within a field, to discuss where *A. rubi* overwinter.

4.3. Statistical analysis

The results from the different registrations were analysed in order to give answers to the questions presented in the introduction. All tests were conducted at significance level $\alpha = 0.05$.

4.3.1. Weevil activity registrations

The results from the counting of severed buds and weevils collected by the beating method, were analysed in different ways:

- The relationship between the two methods was analysed (linear regression analysis) to find the correlation between the two methods.
- Tukey' s tests (Montgomery 1997a) were conducted to discover differences between the different fields of the same age in number of *A. rubi* and severed buds.
- Split plot analyses (Montgomery 1997b; see below) were conducted to discover which factors (grower, age, edge, spraying) that significantly influenced number of *A. rubi* and severed flower buds.
- A two ways variance analysis (ANOVA) was used with the plots as blocks in order to find differences between the rows within a double row.

4.3.2. Yield registrations

The distribution of berries in the different categories was studied for the two age classes and for sprayed and unsprayed plots. The yield registrations were analysed in search for a relationship between the activity of *A. rubi* (severed buds/ weevils found by beating) and the saleable yield. The effect of spraying was investigated by conducting a split plot analysis. In addition, the percentage of the saleable yield harvested at different times in sprayed and unsprayed plots was studied, but no statistical tests were conducted.

4.3.3. Flower trusses registrations

The relationship between the yield and the average number of flower trusses per plot were investigated (linear regression analyses). Furthermore, the relationship between the number of flower trusses and the activity of *A. rubi* (severed buds/ weevils found by beating) was investigated (linear regression analyses). In addition, a new variable, yield per flower truss, was created, and another split plot analysis was conducted to find the factors affecting it, particularly to see if spraying had a significant effect.

4.3.4. Eggs in severed buds

Single buds were examined to see how many eggs they contained. The data from these examinations were compared to the Poisson distribution, and a χ^2-test was performed to see if the distribution was random (Crawley 1993a). Results from the dissection of buds from severed clusters were analysed in the same manner. The degrees of freedom (d.f.) used were the number of measurements minus the number of parameters estimated from the data (Crawley 1993b).

Results from examined buds collected from unsprayed and sprayed plots, and at different dates were compared, using a contingency table as a basis for a χ^2-test (Larsen & Marx, 1990).

4.3.5. Description of split plot design

To discover which factors that significantly influenced the number of *A. rubi*, severed flower buds, saleable yield, and saleable yield per flower truss, split plot analyses were used (Table 4). In the split plot design the grower was the block or replicate, main plots were fields of different ages and the sub-plots consisted of the different insecticide treatment (sprayed or unsprayed) and location within the field (edge or middle). Only grower A, B, C and D could be included in these analyses. Thus, one-way variance analysis (ANOVA) was conducted as well, to be able to include all the data.

Table 4: Factors and variables used in split-plot analysis.

Factor/variable	Description	Values
'Grower'	Four of the seven growers included in this study	A-D
'Age'	The number of years the field has been harvested	1 or 3 years
'Insecticide'	Whether the plots were sprayed with insecticides or not.	Sprayed or unsprayed
'Edge'	Whether the plots were placed near edge vegetation or older strawberry fields	Edge or middle
'No. of *A. rubi*'	The number of *A. rubi* found by using the beating method (average per plant in each plot)	No./ plant
'No.of severed buds'	The number of damaged buds found (average per plant in each plot)	No./ plant
'Saleable yield'	The total weight of berries in the categories >30 mm. and 25-30 mm.	Gram/ plant
'Saleable yield/ flower truss'	'Saleable yield' divided by the average number of flower trusses	Gram/ flower truss

4.4. Sources of error

- The beating method will detect most *A. rubi* when the temperature is high and the weather is nice. Some weevils might have been scared away before the beating was conducted. The third year plants were big, so it was more difficult to detect all the weevils.
- Some of the severed buds may have been overlooked.
- The unsprayed plots were relatively close to the sprayed plot. As a result of this, *A. rubi* might have come from the unsprayed plots to the sprayed ones, and the insecticides might have a larger effect than these registrations shows. The movement could also have been in the opposite direction, since the pyrethroids has a repelling effect (i.e. *A. rubi* that was not killed by the insecticides can have moved from sprayed to unsprayed plots). However, few *A. rubi* moves from one plant to another (Leska 1965). There might have been some drift, so that pesticides affected the unsprayed plots, but there were several meters of 'buffer zone' between where it was applied pesticides and where the registrations were done.
- During harvesting some of the berries (especially the big ones) might have been harvested by the other pickers, but the plots were well marked so this should not happen.

5. Results

This chapter is divided in two parts. The results concerning the biology of *A. rubi* is presented in the first part, and applied aspects in the second part.

5.1. Biology of *A. rubi*

The aspects of the biology of *A. rubi* that have been studied are:

- The spatial distribution
- Oviposition
- Overvintering

5.1.1. The distribution of A. rubi

The distribution of *A. rubi* between fields and within each field is based on both severed buds and beating registrations.

Between field variation

There were big differences from field to field in the number of *A. rubi* and severed buds (Figure 13). In general, third year fields had more *A. rubi* than first year field ($p<0.001$, $n=32$, split plot analysis; $p=0.003$, $n=45$, ANOVA). The same was the case for severed buds ($p<0.001$, $n=32$, split plot, $p=0.005$, $n=45$, ANOVA). Figure 13 also shows that the variable ‘grower’ had a great effect on the weevil activity. Grower B and F had significantly more *A. rubi* than all the other growers, except the third year field at grower A which also had a high amount of *A. rubi.* The number of severed buds varied between the fields in a similar manner as the number of *A.* rubi: The highest number of severed buds was found at grower B and F.

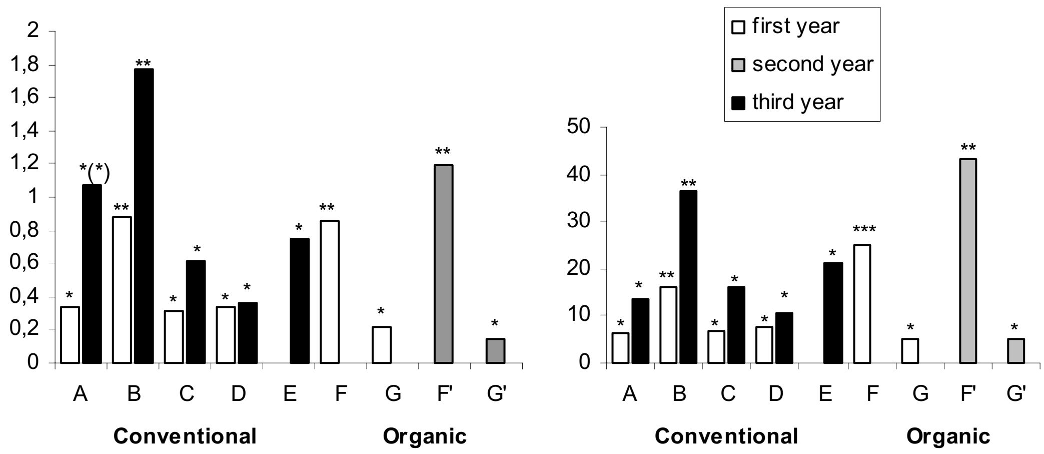


Figure 13: *A. rubi* and severed buds in the 11 fields. A-G are the 7 growers in 2000, F' and G' are the 2001 registrations. The average for each field is based on all plots in the field (cf. Figure 8 and Figure 9). Columns marked with a different number of stars were significantly different according to Tukey's test (each age class analysed separately).

Mid-field vs. edge plots

The mid-field plots were compared with the edge plots within the same field to see how the location in the field influenced the number of *A. rubi* and number of severed buds (Figure 14 and Figure 15). There is on the whole a higher percentage of *A. rubi* in the edge plots (split plot, p=0,038, n=32), especially early in the season in third year plots. Early in the season in the first year plots the difference between edge and middle was less pronounced (Figure 14).

In third year fields the percentage of *A. rubi* in the edge tended to decrease later in the season, while it increased slightly in the sprayed first year fields.

Even though more *A. rubi* were found in the edge than the mid-field the number of severed buds did not follow suit (Figure 15): No significant effect of the edge on the number of severed buds could be found.

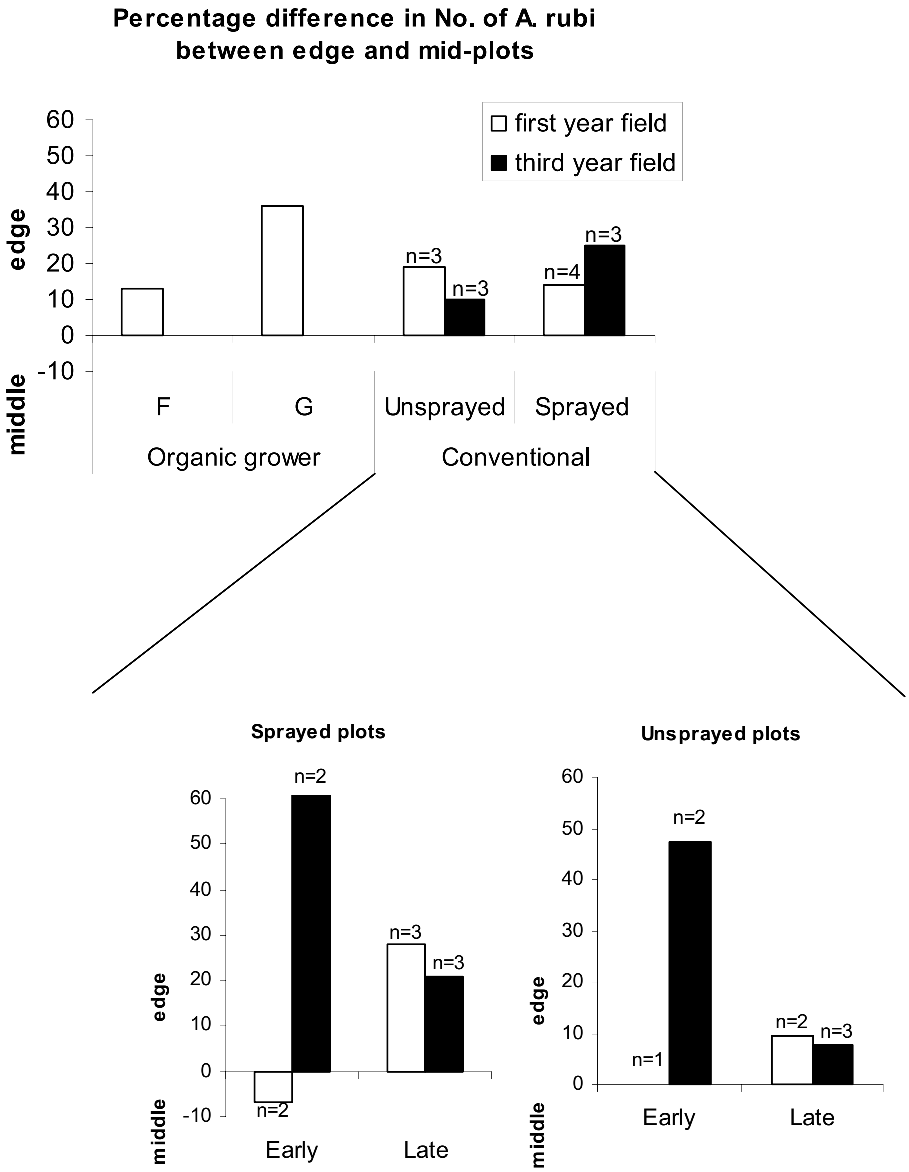


Figure 14: The difference in percent between the number of adult *A. rubi* in edge plots and mid-field plots. Above: The total season. Below: early and late is before spraying and after spraying respectively; conventional plots). Values above zeros show that more *A. rubi* were found in the edge. [1]

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[1] In the organic fields, the percentage difference was calculated using the average number of weevils from the edge and middle plots in each field. The conventional fields had to contain an edge- and a middle plot treated identically (i.e. either sprayed or unsprayed) to be included in the calculations. For practical reasons not all data was available in calculating the differences before insecticide application.

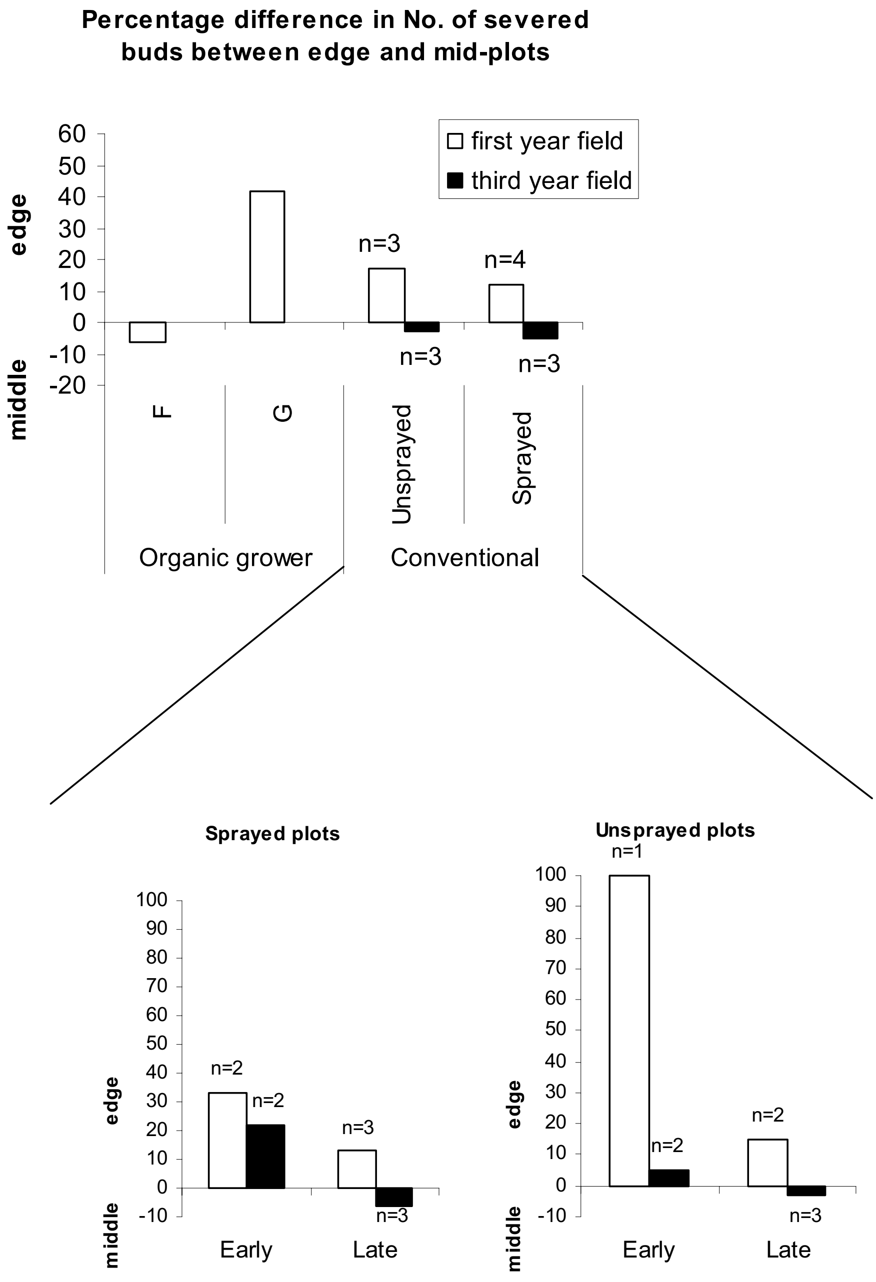


Figure 15: The difference in percent between the number of severed buds in edge plots and mid-field plots. Above: The total season. Below early and late is before and after spraying, respectively (conventional plots). Values above zero show that more severed buds were found in the edge.

Relationship between the two sampling methods in the cultivar 'Korona'

As indicated by the results above, the two methods used for measuring activity of *A. rubi* were highly correlated (R^2=0.70 p<0.01, n=45; Figure 16).

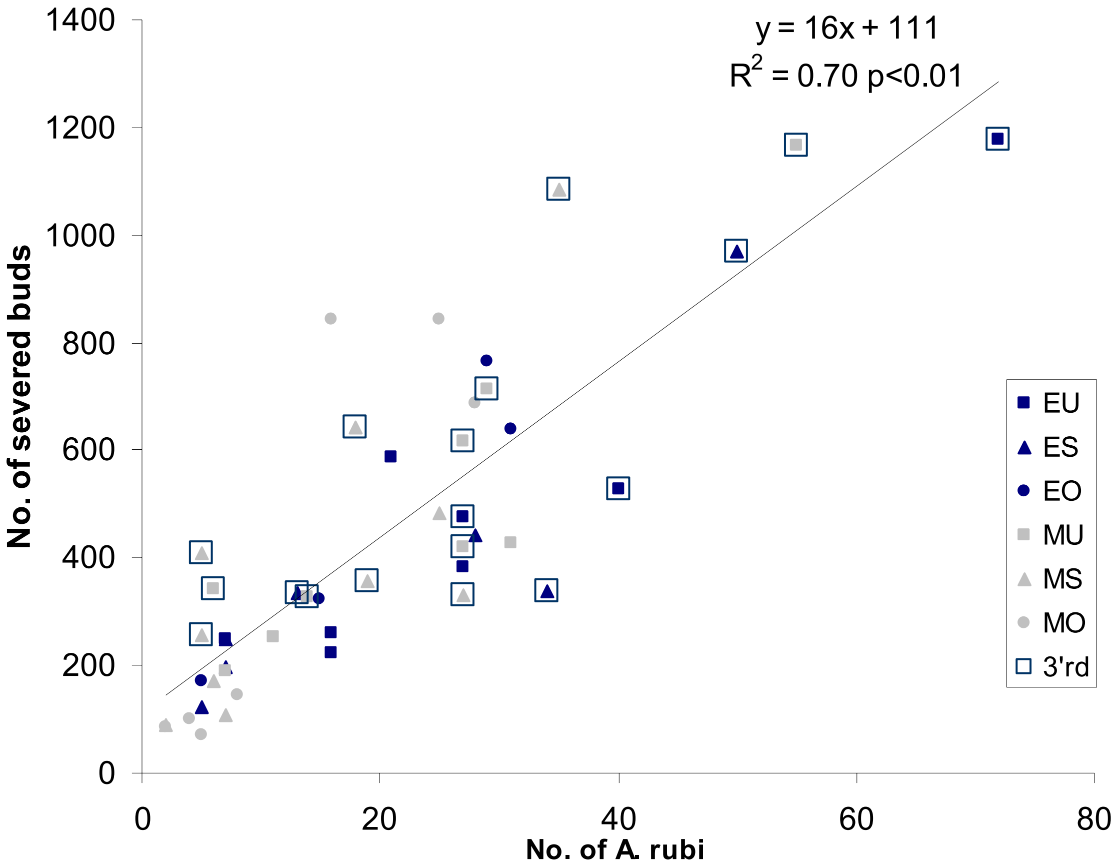


Figure 16: Relationship between the total number of *A. rubi* caught by beating and the total number of severed buds found in the row beside, for all the 45 plots with 'Korona', summer 2000. EU=Edge, unsprayed; ES=edge sprayed; EO=Edge organic field; MU= middle unsprayed; MS= middle sprayed; MO=middle organic. A square around the mark indicates a third year field; no square indicates a first year field.

This means that the number of *A. rubi* explains as much as 70 percent of the variation in the number of severed buds in the adjacent row. The data suggests that 16 severed buds were found for each additional *A. rubi* counted by beating in the adjacent row. This is a minimum number. Since the weevils were replaced after beating, the same weevil could be counted the following weeks. Theoretically, the same weevils could have stayed in the same row the whole season and could have been counted at each sampling. In average 6.5 samplings of *A. rubi* were done, thus one individual found in the beating method would in maximum indicate 104 severed buds in the next row.

In addition, Figure 16 shows that a majority (12 of 19) of the edge plots were below the regression line, i.e. there tended to be less severed buds per *A. rubi* in the edge. This is agreement with the results concerning the distribution within a field: there were not significantly more severed buds in the edge plots even though there were more *A. rubi* in these plots.

Sunny vs. shady side of double row

The number of severed buds was registered separately for each of the rows within the double row most of the flowering season (Table 1, Figure 7). The purpose was to see if the weevil activity (i.e. number of severed buds) in a double row was higher in rows facing south, southwest, or west than in the rows facing north, northeast or east.

First, the total numbers for the whole season was studied. No differences were found (Figure 17, left), but when the data from the first two weeks of registration was studied it was more severed buds in rows facing south south-west and west, than those facing north, north-east and east (Figure 17, right, ANOVA 2 ways, n=90, $p<0.05$).

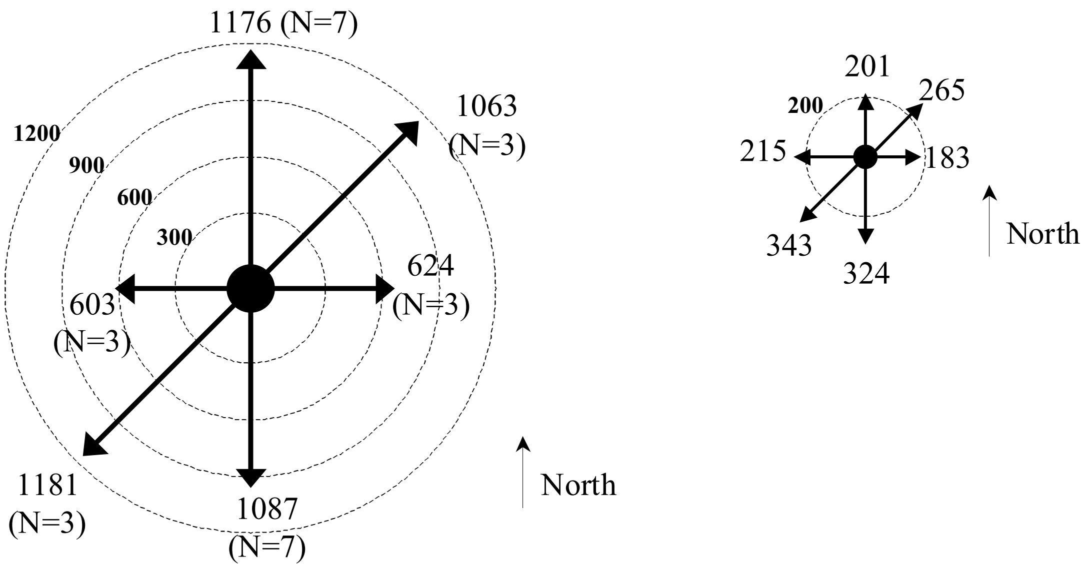


Figure 17: The number of severed buds according to which direction the row is facing. Average per field, data from both years. The whole season (left); the first two weeks of registration (right).

5.1.2. Egg-laying pattern

The results from the dissection of the severed flower buds collected in summer 2000 are presented in Figure 18. As long as there is a surplus of undamaged buds, it is expected to find one egg per severed bud. Most of the single buds contained one egg, and more than twice as many single buds as expected from a random distribution, contained one egg. The distribution of eggs in buds from severed clusters was significantly different from the distribution of eggs in single buds (Poisson distribution $p<0.05$, χ^2-test 3 d.f.). In buds from the clusters, the eggs were distributed randomly, and most of the buds did not contain any eggs at all.

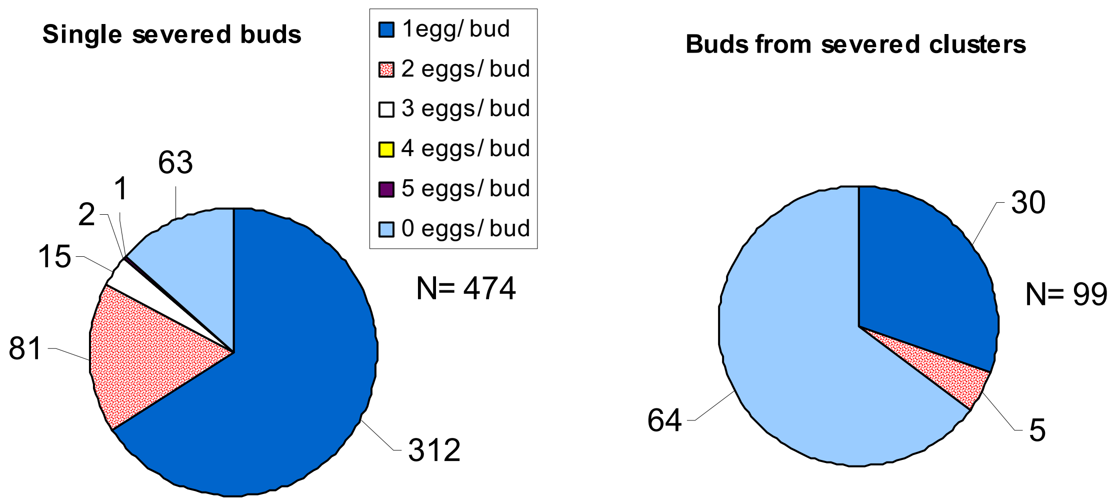


Figure 18: The distribution of eggs of *A. rubi* per severed strawberry bud (2000). Pooled data from unsprayed and sprayed plots and different farms (see Table 2).

The egg-laying pattern in the single buds from sprayed and unsprayed plots (Figure 19) was compared to see if the spraying influenced the number of eggs per bud. No statistical difference was found ($p>0.05$, χ^2-test, 4 d.f.).

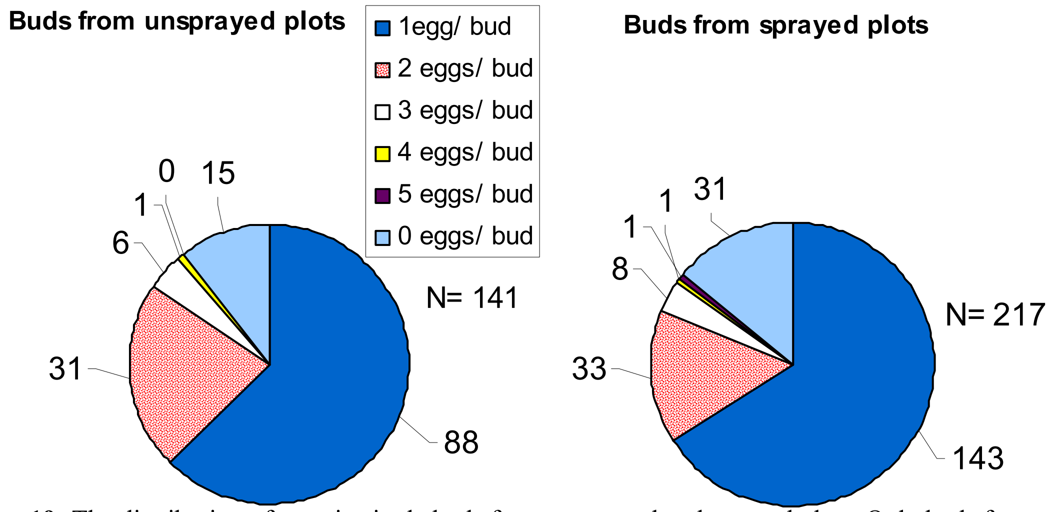
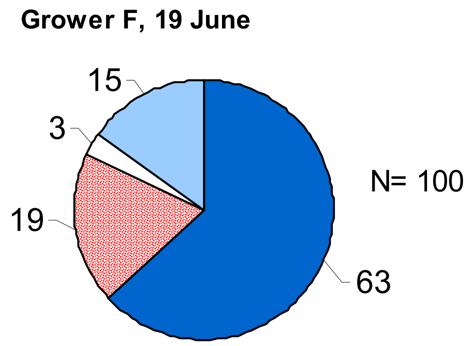


Figure 19: The distribution of eggs in single buds from unsprayed and sprayed plots. Only buds from conventional plots are included.

Date:	Grower:	Average per plot: Severed buds	A. rubi
19. june	F	1503	31
04. june	G	230	11
24. june	G	344	6



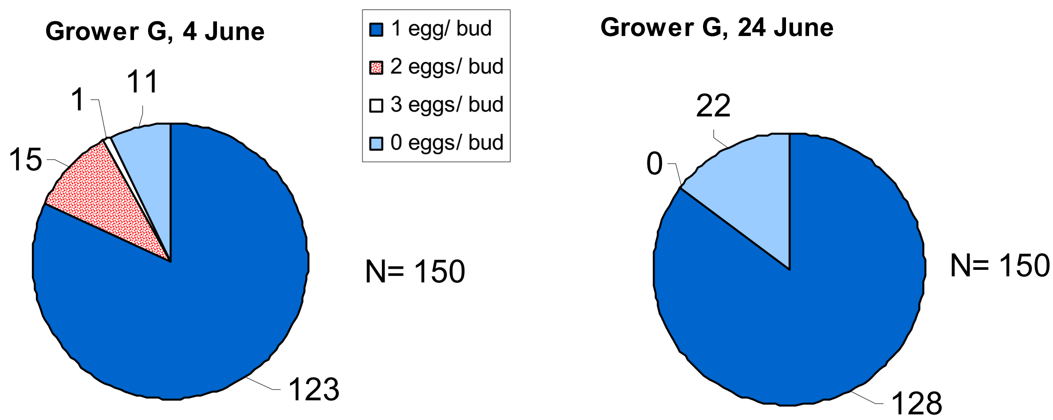


Figure 20: The distribution of eggs of *A. rubi* per severed strawberry bud in the organic fields in 2001. All data for each field at each date are pooled.

Figure 20 shows the distribution of eggs in single buds that were collected in the two organic fields in summer 2001. In field G, buds were collected both early and late in the flowering season to see if time had an influence on the distribution of eggs in buds. There was a statistical difference in the distribution of eggs between the buds that was collected early and late in June ($p<0.05$, χ^2-test, 2 d.f.). Late in June there tended to be fewer buds with two or three eggs, and more buds with one or zero eggs.

5.1.3. Spring litter samples

The spring litter samples from grower G yielded only one *A. rubi* (male). This specimen was found in samples of natural leaves from the edge vegetation. In these samples relatively many other weevil species were found. In the edge samples consisting of strawberry leaf litter from the field, no *A. rubi* or other weevils were found. Neither were any weevils found in the samples from the middle of the field. Because the plants were small, very little material was produced and not much leaf litter was collected from within the field compared with the edge vegetation.

5.2. Applied aspects

In this second part, the results concerning applied aspects are presented.

5.2.1. Relationship between the activity of *A. rubi* and the yield

First, the relationship between the two earliest registrations of the *A. rubi* activity and the total yield was examined to see if the grower at an early stage could say anything about the yield loss *A. rubi* would cause. In addition, the relationship between the first three weeks of activity registrations and the first three weeks of the harvesting was looked into, and then the relationship between the total numbers from the whole season was investigated.

A statistically significant relationship was found between early season number of severed buds and the yield in third year fields (R^2=0.51 $p<0.01$). However, this relationship was not as expected: More severed buds in the two first registrations was associated with a higher total saleable yield (Figure 21). No significant relationships were found in first year fields or between the number of weevils and the yield.

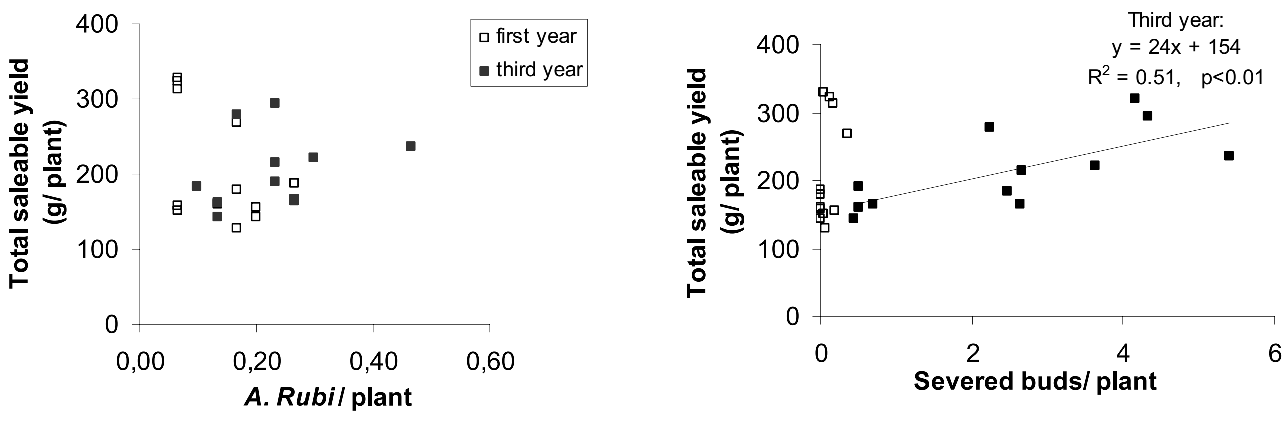


Figure 21: The relationship between the first two weeks of *A. rubi* registrations and the total saleable yield (left); the first two weeks of severed buds registration and the total saleable yield (right).

A statistically significant relationship between the three first weeks of *A. rubi* registrations and the yield from the first three weeks of harvesting could be found in the first year fields (R^2=0.46 p=0.02). Again the correlation was positive: More weevils was correlated with a higher saleable yield (Figure 22).

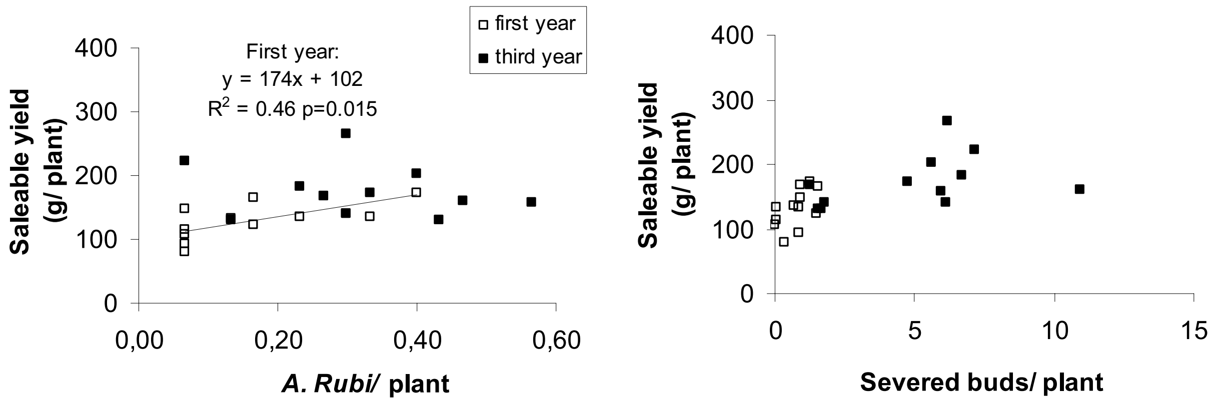


Figure 22: The relationship between the first three weeks of *A. rubi* registrations and the saleable yield from the first three weeks of harvesting (left); the first three weeks of severed buds registration and the saleable yield from the first three weeks of harvesting (right).

A statistically significant relationship between the total number of *A. rubi* and the total saleable yield could be found in the third year fields (R^2=0.37 p=0.04). This time the correlation was negative: More *A. rubi* was associated with a lower saleable yield (Figure 23).

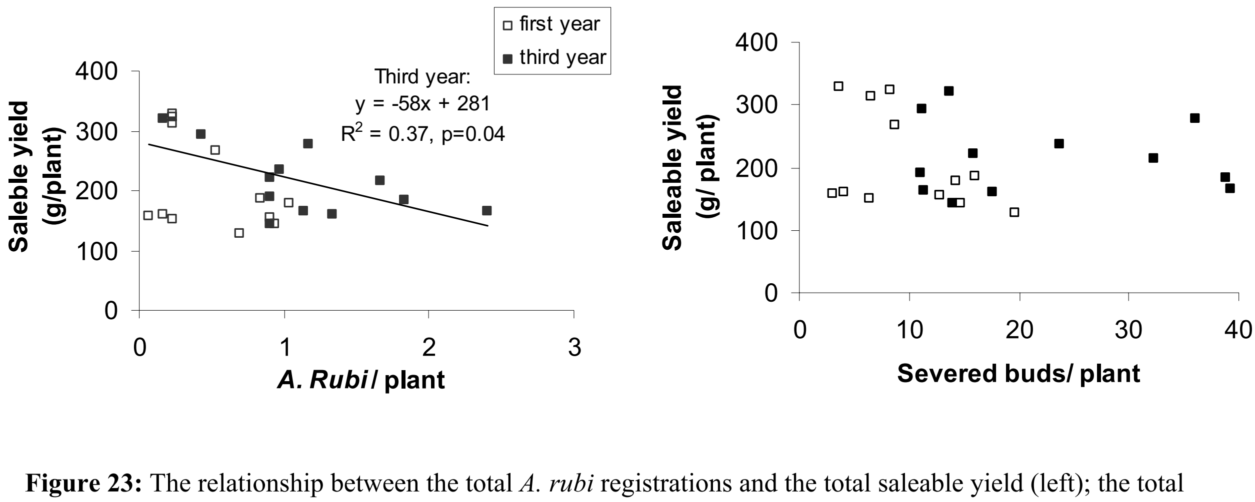


Figure 23: The relationship between the total *A. rubi* registrations and the total saleable yield (left); the total severed buds registration and the total saleable yield (right).

5.2.2. Effect of pesticides

Effect on berries (size, weight and condition)

How the berries were distributed among the different yield categories (big, medium, small and rotten) is shown in Figure 24. No statistical analyses were done, but the age of the field seemed to influence the distribution of berries more than insecticides. The 2000 season was wet with a lot of rotten berries, and of the registered berries 20-25% were not saleable because of rot (*Botrytis*) (Figure 24).

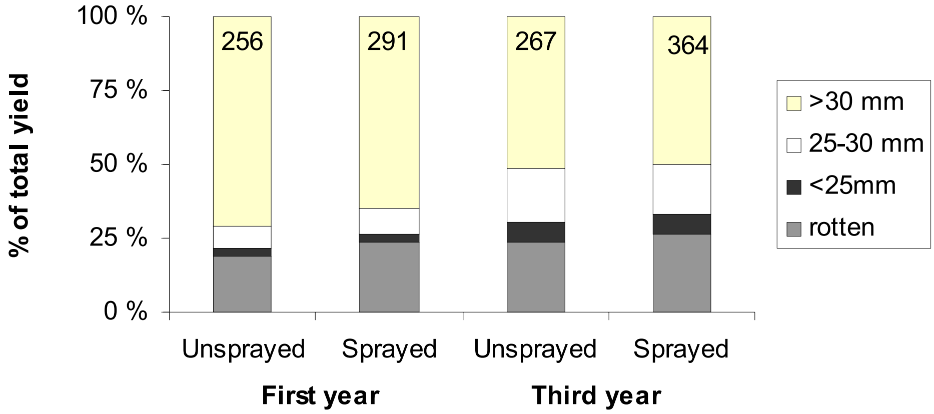


Figure 24: The percentage of berries in different yield categories. The number at the top of each column indicates the total yield per plant (average from farmer A, B and C). N= 6 plots for each column.

The amount of berries in the different yield categories was also examined separately for the three different growers The data (Appendix 4) show that there tended to be differences in the distribution of berries in the four categories between the fields, but within the same field the differences between unsprayed and sprayed plots were smaller.

Effect on the weevils, severed buds and yield

The regression lines for sprayed and unsprayed plots were almost identical (Figure 16). This suggests that one *A. rubi* damages the same number of buds in sprayed and unsprayed plots.

Even though the insecticides did not reduce the damage made by each *A. rubi*, they increased the yield and decreased the number of weevils and severed buds. A significant effect of pesticides was found on the number of *A. rubi* ($p=0.005$, $n=32$), the number of severed buds (p<0.001, n=32) and the yield (p<0.001, n=32) (split plot analysis). Overall there was a 32% reduction in the number of *A. rubi*, a 21% reduction in the number of severed buds and a 16% decrease in yield in unsprayed plots compared with sprayed plots.

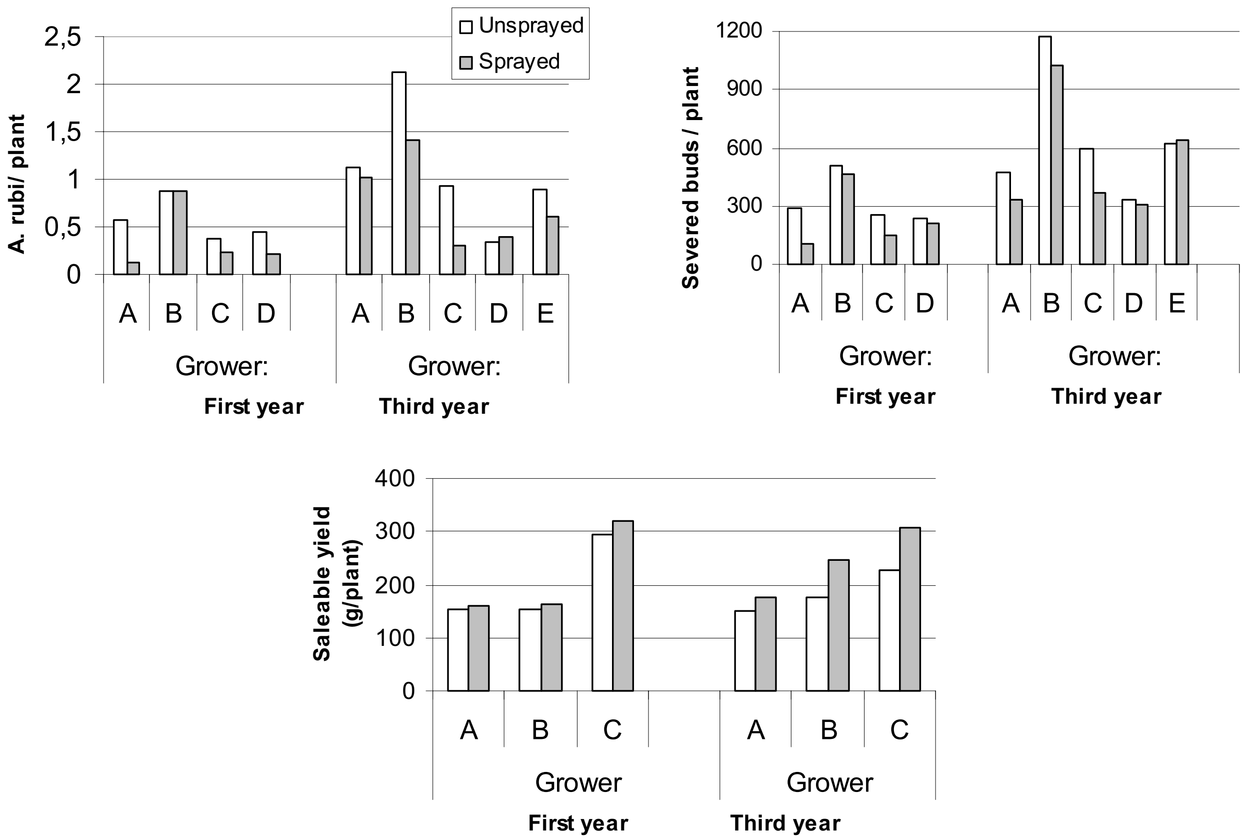


Figure 25: The number of *A. rubi,* severed buds and the total saleable yield in the different fields. Each column represents the average of the two sprayed or unsprayed (cf. legend) plots in each field.

Differences between first and third year fields

An interaction effect between the age of the field and the benefit pesticides had on the yield was found (split plot, p=0.02). The insecticides had a larger effect in third year fields than in first year fields. If no insecticides were applied, the yield was greater in the first year plots than in third year plots, while in sprayed plots, the yield was higher in the third year plots than in first year plots (Figure 26). This can be seen in Figure 25 as well. The first year fields had in total a 6% lower yield in the unsprayed plots than in the sprayed plots, while the corresponding percentage for third year fields was 24.

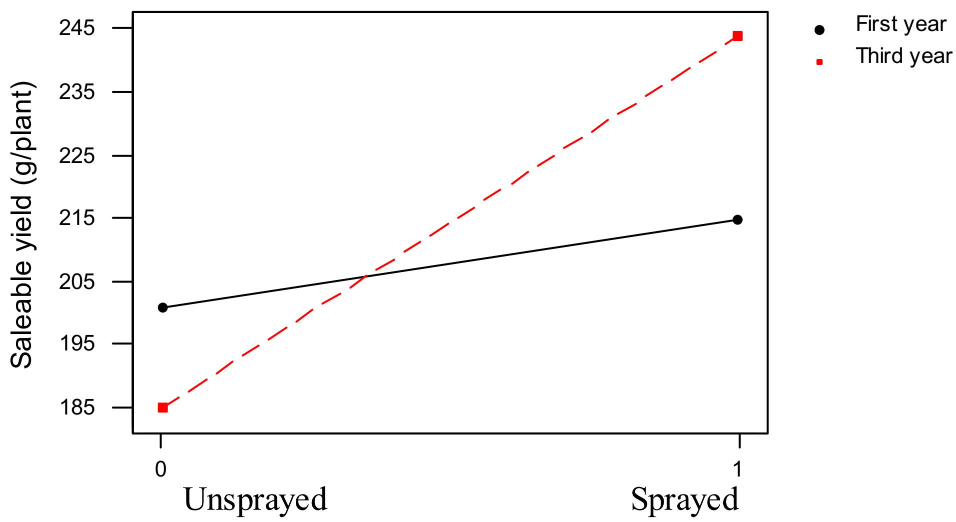


Figure 26: Different effect of spraying in first year plants and third year plots.

Time of harvesting

The severing of buds might cause a delay in harvesting. Thus, in sprayed plots where less buds were severed, a higher percentage of the yield might have been harvested earlier.

Figure 27 shows that spraying did not lead to any earlier harvest. The percentage of berries harvested was approximately the same in unsprayed and sprayed fields during the whole season.

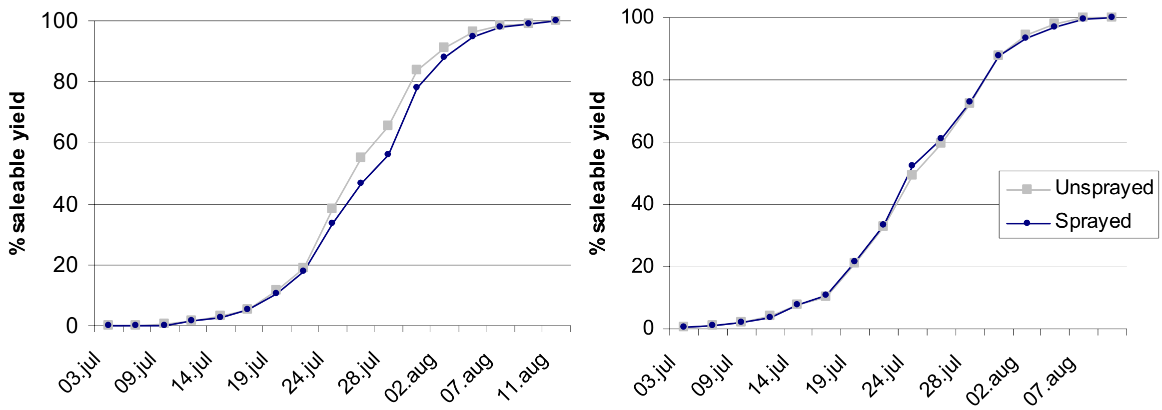


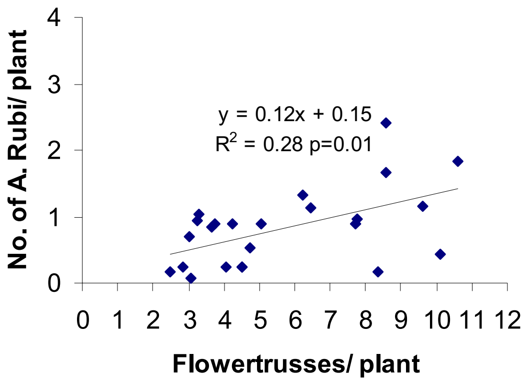
Figure 27: Cumulative saleable yield in sprayed and unsprayed plots. First year fields (left) and third years fields (right). Pooled data for grower A, B and C. N=24.

5.2.3. Flower trusses

The number of flower trusses varied a lot, especially between first and third years fields, but also between plots of the same age. We wanted to see if and how this variation affected the results.

Relationship between weevil activity and flower trusses

A statistical correlation was found between the number flower trusses per plant and weevil activity. The relationship was strongest between the number of severed buds and the number of flower trusses (R^2=0.49): One extra flower truss gave three additional severed buds.



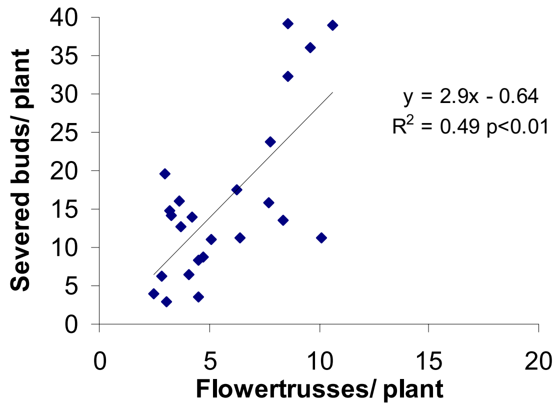


Figure 28: Relationships between weevil activity and flower trusses per plant.

Number of flower trusses and yield

Not surprisingly, regression analysis revealed a strong relationship between the number of flower trusses and the yield both in first year and third year fields. In first year fields the number of flower buds explain as much as 73% of the variation in marketable yield (Figure 29).

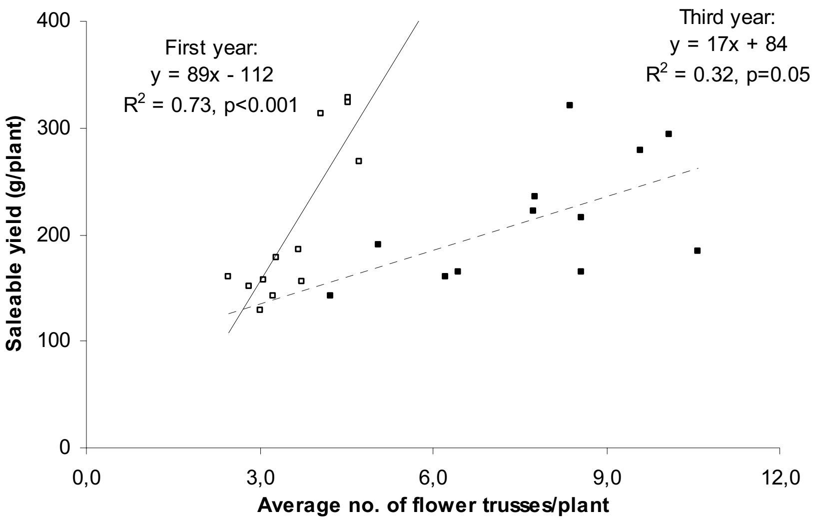


Figure 29: Relationship between the saleable yield and the number of flower trusses for the 24 plots.

Effect of weevil activity on yield per flower truss

A relationship between number of severed buds and yield per flower truss, as well as between weevils and yield per flower truss was found both in first and third years fields (Figure 30). The effect of the *A. rubi* activity on the 'yield per flower truss' in first year fields tended to be higher than in third year fields (steeper slope).

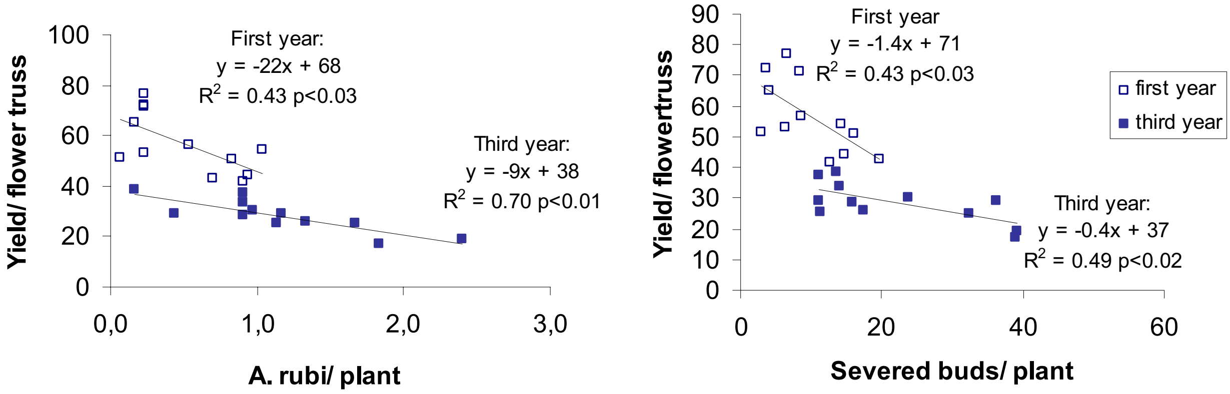


Figure 30: Relationship between the number of *A. rubi* found by beating and the yield per flower truss (left) and the number of severed bud sampled and the yield per flower truss (right).

Effect of spraying on yield per flower truss

A new split plot analysis was conducted to see if the pesticides also had an effect on the yield per flower truss. It tended to be a higher yield per flower truss in sprayed fields (Figure 31) and the effect of spraying was almost statistically significant (p=0.054).

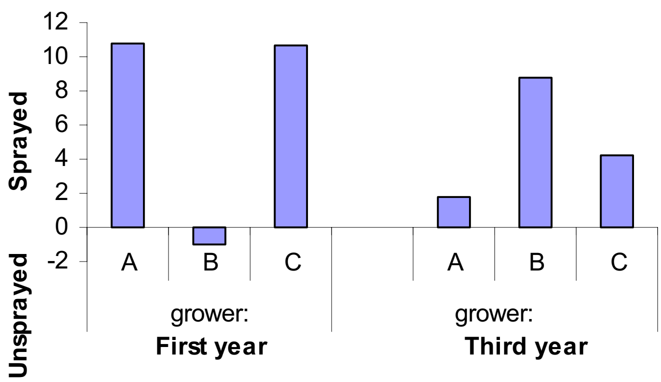


Figure 31: Difference in yield per flower truss between sprayed and unsprayed plots. Values above zero indicate a higher yield in sprayed plots.

5.2.4. Organic fields

First the two methods of cultivation will be compared, and then the results from the organic field of cultivars are presented.

Comparison conventional and organic fields

The results from the organic fields are included in, Figure 13, Figure 14 and Figure 15. The organic fields did not stand out from the conventional fields in either the amount of *A. rubi* or severed buds (Figure 13). The variation was bigger between the different fields, than between the two methods of cultivation. No differences in the distribution of *A. rubi* and severed buds were found between the organic and conventional fields (Figure 14 and Figure 15). The results from the organic fields in 2001 (

Figure **32**) verify the main results from 2000 (Figure 16), and the graph shows a high correlation between the *A. rubi* found by beating and the severed buds counted in the row beside (R^2=95, P<0.01, n=11). The data suggests that the number of severed buds per *A. rubi* might be slightly higher in the organic fields than in the conventional fields, and indicate that 35 severed buds are found for each additional *A. rubi* counted by beating in the adjacent row.

At grower F in 2000, the relationship between *A. rubi* and severed buds appeared to be negative (R^2= 0.58, p=0.13, n=5) the more *A. rubi* the less severed buds (see the 5 organic points above the regression line; Figure 16). This was a strange result and led to further registrations in the organic fields. However, the year after the relationship tended to be positive (R^2= 0.28, p=0.36, n=5) in this field as well (

Figure **32**).

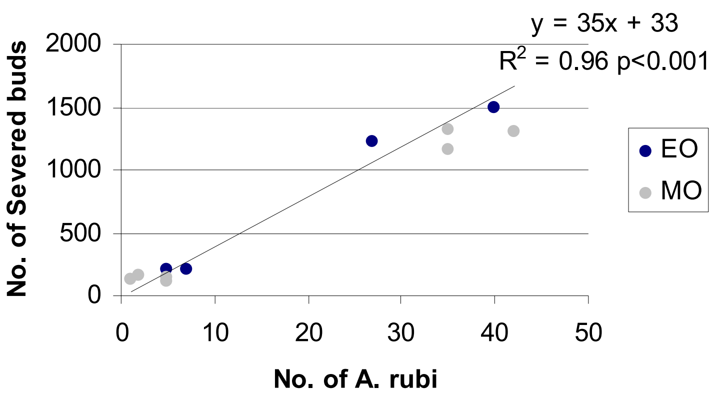


Figure 32: Relationship between the number of *A. rubi* and severed buds. The 11 organic plots, summer 2001. EO=Edge organic field; MO=mid-field organic. All the plots were in their second year of production.

Organic field of cultivars

The results from the registrations of severed buds and weevils in the organic field of cultivars at grower F was investigated to see if the relationship between the beating method and number of severed buds varied in different cultivars (Figure 33). In contrast to Figure 16, Figure 33 presents the relationship between the two sampling methods based on two single registrations and not totals from the whole season. The figure suggests that there were more severed buds per adult *A. rubi* found by beating in the cultivar ‘Korona’, than in the three other cultivars (‘Oda’, ‘Inga’ and ‘Bounty’). Due to the low number of registrations, no certain conclusions can be drawn from these observations.

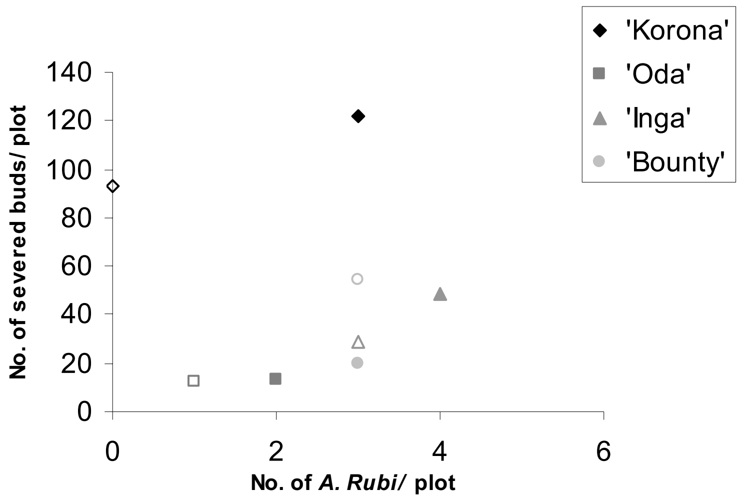


Figure 33: The relationship between the number of *A. rubi* found by beating and severed buds found in four strawberry cultivars, on two different days. Closed symbol 23 May; open symbol 31 May.

6. Discussion

The results concerning the biology of *A. rubi* are discussed and compared with results from other investigations. Under applied aspects, factors influencing the yield and consequences for pest management of *A. rubi* are discussed (action threshold etc.)

6.1. Biology of *A. rubi*

A short assessment of why the weevil activity varies within fields, and between growers and age classes is provided. Then, some of the properties influencing the number of *A. rubi* and severed buds are evaluated, before the egg-laying of this weevil is discussed.

6.1.1. Spatial distribution of adult *A. rubi* and severed buds

The distribution of weevil activity was registered during the flowering period (May- June).

Between growers

The factor 'grower' seems to be the most important factor in explaining the variation of the amount of *A. rubi*, severed buds and yield from field to field. The factor 'grower' embraces all the things the grower influences (except edge and cultivar), such as plant quality (e.g. number of flower trusses), crop rotation, use of fertilizers and pesticides. In addition, all aspects of the field location are embedded in this factor: soil, local climate, edge vegetation, distance to other strawberry fields (degree of isolation etc.).

Between age classes

The age of the field was an important factor in determining the weevil activity. As expected there were more *A. rubi* and severed buds in third year fields than in first year fields. Hibernation sites in or near the field and relatively little dispersal, can explain these differences between the age classes.

Within a field

On the whole more weevils and severed buds were found in the edge plots. This was no surprise, since old and new literatures suggest that the weevils migrate into the field from the edge vegetation in the spring. Jary (1932) writes that the weevils were first found on those plants close to the hedgerows, and according to Lövhult (1998) the damage was highest where there was a lot of vegetation (often with wild raspberry) around the field. Also most of the oviposition activity of *A. signatus* (the American strawberry bud weevil) occurred in the rows adjacent to ‘unmowed’ weeds with cultivated raspberry behind (Kovach et al. 1999).

6.1.2. Properties influencing the number of *A. rubi* and severed buds

Properties both outside and inside the fields might influence the number of *A. rubi* and severed buds:

Edge vegetation

A. rubi is influenced by the edge vegetation (outside the field) in many ways. It can be important for feeding, oviposition and providing hibernation sites, both for the weevil and its natural enemies. Different edge vegetation can explain some of the variation in the number of *A. rubi* between the fields. Raspberry, for example, is a source of *A. rubi* (Alford 1984). But weevils from the small raspberry buds are not able to deposit as many eggs (i.e. severe so many buds) as those developed from strawberry buds (Lekic 1963).

More *A. rubi* was found in field near the edge than in the middle of the field, while the number of severed buds in the edge was not correspondingly high. The reason for this could be that:

- A higher portion of the weevils in the edge might have been males (*A. rubi* caught by beating were not sexed).
- Some of the weevils caught in the edge might occur in the edge for other reasons than oviposition, for example: feeding, mating, or dispersal (i.e. they were on their way further into the field, and were just passing by).
- Weevils were harder to catch by the beating method in the middle than in the edge. The last suggestion is not a very plausible explanation.

Hibernation sites

The overwintering site is important for the distribution of weevils and severed buds between fields, age classes and within the fields. According to the literature, overwintering *A. rubi* has been found both in and outside the field (Lindblom 1930, Jary 1932, Leska 1965, Stenseth 1991, Svensson 1999).

The increase in the *A. rubi* population in third year fields indicates that the newly hatched weevils overwintered in or nearby the field. But the survival rate was probably higher outside the field since more weevils were found in the edge plots. Another reason for the higher percentage of *A. rubi* in the edge plots can have been that the weevils migrated out of the field to feed on the edge vegetation in the early in the spring.

If the strawberry blossom weevil can overwinter within the fields (Svensson 1999), it will be a build up of resident weevils in the field from year to year. Therefore, the difference between edge and middle is expected to be more pronounced in the first year fields (where none of the weevils are resident) than in the third year fields, particularly early in the season. The most evident trend in the data pointed in the opposite direction. Maybe most of the weevils came into the first year fields after spraying. It could also have been of significance that the plants in the third year fields developed earlier in the spring (pers. obs.) and provided more buds than plants in the first year fields. As a consequence, *A. rubi* might have preferred third year fields early in the season. It has to be mentioned that the distribution of *A. rubi* and severed buds before spraying, was based on little data.

Only one adult *A. rubi* was found in the spring litter samples, and this specimen was discovered in a sample of leaves taken from the edge vegetation (i.e. outside the field). There are several reasons for the low catch in the overwintering samples:

- Too little litter was sampled. Cross et al. (2000) conducted experiments where litter was collected in search for *A. rubi.* Even though they collected several sacks of litter from hedges adjacent to a field that had been heavily infested, only 5 adult strawberry blossom weevils were found.
- It had been a very wet autumn (2000). According to Jary (1932), *A. rubi* overwinter in dry leaves, thus a higher number of *A. rubi* than usual probably not survived throughout the winter. Thorough investigations on a closely related species on apple

(*Anthonomus pomorum*), show that the highest mortality during overwintering was beneath wet leaf litter, while the highest survival was beneath dry leaf litter (Toepfer et al. 2000). *A. pomorum* preferred leaf litter over all other substrates (i.e. rough and smoth bark, grass and pure soil; Toepfer et al. 2000).

No conclusions can be drawn from the spring litter samples alone, except that emergency traps probably can be used in an effort to detect overwintering *A. rubi* if more material is collected.

Plant quality (i.e. number of flower trusses)

The number of flower trusses did influence both the number of severed buds and *A. rubi,* but it was of greatest importance for the number of severed buds. The plant quality varies from field to field. Generally, older plants have more flower trusses, thus more severed buds are found in older fields. How the plant quality influences the yield is discussed later.

Microclimate within the field

Stenseth (1991) investigated the temperature in various parts of strawberry fields. The temperature was lowest on the soil surface on the northern side of the row, and highest between plant litter on the southern side of the row. The differences were biggest on sunny days before flowering. He also showed that the emergence of weevils in strawberry fields is dependent on the temperature. The results from my fieldwork are consistent with the temperature results of Stenseth (1991). Early in the season there was a higher activity in the rows facing south or west than in those facing north or east, because of a higher temperature and consequently *A. rubi* was more active. As the season progressed and temperatures in general were higher, these differences evened out.

6.1.3. Egg-laying

Severed buds per female

Even though a high relationship between *A. rubi* (counted by beating) and severed buds was found, this does not give the absolute number of severed buds each female *A. rubi* causes. The relationship was found using total numbers (of *A. rubi* and severed buds) for the whole season. The same weevils might have been counted several times. Even assuming no weevils are counted more than once, some of the weevils have probably not been caught in the beating tray at all, and in addition, a number of the ones counted were likely males. According to Lekic (1963) the sexual ratio in *A. rubi* populations varied between 0.38 and 0.54. This ratio probably changes with time as the males might die off earlier than females. For practical reasons the two methods were used in adjacent rows, not the same row. Whether the weevils stay in the same row (especially after being disturbed by beating) or how neighbouring rows differ in weevil number is not known. Furthermore, the egg-laying capacity varies according to the bud size and host plant where the weevil developed (Lekic 1963), so there is probably great variation between the females in the number of buds they cut off.

Table 5 shows results from other investigations on the egg-laying of *A. rubi.* There are big differences between the minimum and the maximum number of eggs per weevil. This present study indicated that 16-104 buds were severed per female, which is within the range of the other studies.

Table 5: The egg-laying capasity of *A. rubi* in strawberry.

	Eggs per weevil:	Comment:
Simpson et al. 1997	Max 187	Female caged over strawberry plants
Leska, 1965	Mean 60 (max 80)	In field
	Mean 35 (max 77)	Under experimental conditions
Lekic, 1963	Max 260	As cited in Stenseth, 1970
Jary, 1932	Minimum 30	(According to dissection of ovaries)

Eggs per severed bud

The distribution of eggs varied between single buds and severed clusters.

Eggs in severed single buds

Analyses of the distribution of eggs in severed single buds, indicated that it was most common to deposit one egg per bud, before the flower stalk was punctured. This is in agreement with earlier investigations of severed buds (Table 6).

Table 6: The number of eggs in severed buds from three investigations, compared with the results from the fieldwork 2000.

	0 egg	1 egg	2 –3	3-5 eggs
Jary, 1932:	Occurs	Most common	Happens	Only under experimental conditions
Leska, 1965:	-	Usually	Rarely	Only in laboratory
Popov, 1996a:	0	85%	13,5%	1,5%
Present study:	13%	66%	17%	4% (in field)

Even though there was normally one egg in a bud, 21% of the buds examined in 2000 contained more than one egg. Jary (1932) said it was unusual to find more than one egg in a single bud. If it happened, it was due to another weevil laying an egg in the same bud a short time after the first egg had been laid (Jary 1932). Because only one larva can complete its development in a flower bud, the population will be regulated by intraspecific competition in dense populations (Lekic 1963). Hence, the finds of buds with several eggs in the present study, indicate the presence of intraspecific competition. According to Jary (1932), four or five eggs in a single bud happened only under experimental conditions with bud shortage. Popov (1996a) agreed, and discovered that the number of eggs in a flower increased with the density of *A. rubi*. These theories can explain why the distribution of eggs varied throughout the 2001 season: Early in the season there were most likely too few buds in the right stage of development available. Furthermore, the females might have large supplies of ‘unlaid eggs’ at this time. Thus, in some buds more than one egg was found. Later, more buds were probably available, and in addition fewer *A. rubi* were detected. As a result, no more than one egg was laid in each severed bud.

However, severed buds that did not appear to have been used for oviposition were also discovered. Jary (1932) was the only one who mentioned this phenomenon (Table 6). He suggested that such empty buds were registered because the egg or larvae in them could have been hidden. Otherwise some of the buds may have been cut off as a result of a feeding puncture (Jary 1932). Generally the empty buds I examined showed no sign of punctures made by *A. rubi.* Thus, most of these buds without any eggs, were probably results of feeding punctures.

Eggs in severed clusters

Not surprising, no eggs were found in most of the buds (i.e. 65%) from the severed clusters. The severed flower clusters might be a result of the weevil puncturing the stalk further down than usual (after egg-laying), or of pure feeding activity. Six of the twenty-seven clusters that were examined contained no eggs. Thus, these are most likely results of pure feeding activity. Whether the remaining 21 clusters were caused by; 1) feeding punctures in combination with egg-laying without severing the stalk, or 2) by puncturing the stalk ‘too far’ down after oviposition, is uncertain. It depends on how common it is to deposit eggs without severing the flower stalk (see below). Literature about observations of severed clusters caused by *A. rubi*’s egg-laying has not been found. But Jary (1932) reported that flower stalks could be severed during feeding.

Egg-laying without severing the stalk

Open flowers that had a dark spot by the base of the receptacle were observed. A larva was observed in some of these flowers when examined. Berries that developed from these flowers were deformed (Figure 34).

Figure 34: *A. rubi* larvae developing in open flowers (i.e. ‘unsevered’ flower buds) caused such deformed berries.

These observations are in accordance with the description of *A. rubi* damage in open flowers given by Hellqvist & Winter (1992), so the larvae were probably larvae of *A. rubi*. This phenomenon was seen in several of the fields, and these observations together with observations of eggs in severed clusters (discussed above), indicated that the flower stalk was not always punctured after an egg had been deposited. It could be that the weevil was disturbed before it had time to puncture the stalk, or it might be a part of the normal behavioural repertoire of *A. rubi*. In fields in the western parts of Norway, quite a large number of the buds with no sign of damage can contain *A. rubi* eggs (T. Våge pers. comm.). Of 100 undamaged buds chosen at random, she found that 40% contained eggs. If the severed clusters found during my fieldwork were caused by accidental feeding punctures, the distribution of eggs in these clusters would show the frequency of *A. rubi* laying an egg without puncturing the stalk. Of the 99 buds in clusters, 35% contained one or two eggs, and this proportion is close to the one observed by Våge. One must keep in mind that the cluster was severed, and this indicates the presence of *A. rubi*. Thus, the chance of finding eggs was higher than if clusters were cut at random by hand.

Even though 30-40% of the healthy buds might have contained eggs, open flowers with a dark spot by the base of receptacle were not very widespread in the fields, and far fewer such flowers were observed than severed buds throughout the season (summers 2000 and 2001). Maybe the eggs failed to develop any further in buds that opened. The number of larvae in open flowers might vary throughout the season. According to Hellqvist & Winter (1992), more *A. rubi* larvae in open flowers than severed buds were observed early in the season, while the 'normal' symptoms were more common later in the season. Hellqvist and Winter (1992), suggested that the pyrethroids used, repelled the weevils from puncturing the stalk. Another possibility is that the flower stalk might be too short to be severed early in the season.

The survival among eggs deposited without puncturing the flower stalk has not been investigated. Most authors agree that severing the bud is necessary to secure the survival of the progeny: In an open flower the immature weevil is more exposed to predators and parasites (Burke 1976), falling to the ground (Blümel 1989 Burke 1976, Lindblom 1930, Tullgren 1914), damage by the sunlight (Tullgren 1914) and dehydration (Blümel 1989, Lekic 1962). Dehydration is the most serious mortality factor in the first and second larval, while the larva is hardier in its third stage (Jary, 1932; laboratory work). Despite all these mortality factors, larvae were found in most of the attacked flowers in Sweden even though it was a very dry and hot summer (2-3ºC over normal; Hellqvist & Winter 1992). The authors suggest that the living flower provides enough humidity.

6.2. Applied aspects

In this second part of the discussion, a number of applied aspects are taken up. One major concern is how the weevils and insecticides influence the yield. How the number of flower trusses influences the yield and the other results are also discussed, and an overview of all the studied relationships is given. In addition, the existing action threshold and the beating method are evaluated, and at the end some practical consequences of the results on possible control methods are suggested.

6.2.1. The weevils effect on the total saleable yield

None of the methods used to measure weevil activity (beating and severed buds) could predict the yield loss very well (not by registrations before flowering, nor by longer registration periods; Table 7).

Table 7: Analysis A: early weevil sampling. Analysis B: the first three weeks. Analysis C: total season. Analysis D: total season, but relationship between weevil activity and yield per flower-truss. '+' and '÷ ' indicates positive and negative statistical relationship, respectively. ns: the relationship is not statistically significant.

Regression analysis:	Relationship between severed buds and saleable yield		Relationship between *A. rubi* and saleable yield	
	First year:	Third year:	First year:	Third year:
A	ns	+	ns	ns
B	+	ns	ns	ns
C	ns	ns	ns	÷
D	÷	÷	÷	÷

Other factors than the strawberry blossom weevil were most likely more important in influencing the yield. One, and probably the most important factor, was the number of flower trusses. In addition to the obvious fact that plants with more flowers had a higher yield potential, plants with many flower trusses had the ability to compensate for damage by the weevil (Cross & Burgess 1998, Blümel 1998). Other insect pests of strawberry, for example mites, may affect the plants so that they do not produce so many flower trusses. The strawberry weevils probably have no such effect on the plant, but might severe some flower trusses during feeding (Jary 1932, pers. obs. of severed clusters). Ideally, the percentage of severed buds should have been registered. But the problem is that this would have been very time consuming; much fewer registrations could have been have carried out in my study and anyway, the strawberry growers will probably not have time to do the counting in practice.

Even though the relationship between *A. rubi* and the total saleable yield is uncertain, the weevils had a negative effect on the yield per flower truss (Table 7). The plants in first year fields were more affected by weevil activity, and had probably less ability to compensate. In third year fields, on the other hand, the negative effect of the weevil was much less. These older plants may have had a higher ability to compensate. This is in agreement with a Swiss experiment (Terrettaz et al. 1995) which shows that one year old plants of Elsanta could sustain 10% removal of their flower buds without significantly affecting the yield, while two year old plants could compensate for up to 30% flower removal.

In third years fields the damage by the strawberry blossom weevil could perhaps result in a higher yield when the number of flower trusses exceeds a certain threshold, while the effect of the weevil on plants with fewer flower trusses might be lower yield. When plants with both few and many flower trusses are studied the average will be that *A. rubi* has no or little effect on the yield (Figure 35).

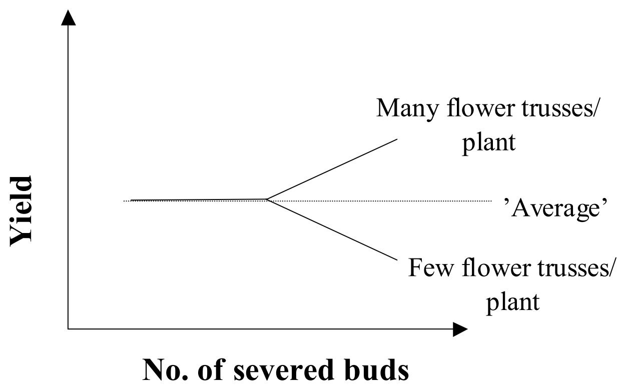


Figure 35: Possible relationship between No.of flower trusses and yield in third year fields.

6.2.2. Effect of insecticides

Insecticides are applied because they are expected to strongly reduce the number of *A. rubi* in the fields, this reduction will lead to less bud damage and a higher yield. In addition weevils are suspected to delay the time of harvesting, and reduce the amount of large berries, because the first buds to develop, the primary buds, are damaged.

Effect on berries (size, weight and condition)

Recent research in the cultivar 'Elsanta' shows that the size of the berries increases when flower buds are removed. Cross & Burgess (1998) reported that the mean berry weight increased up to 11%, and the percentage of fruit (by number) in class one increased from 67% to 72% in response to removal of up to 12 buds per plant. Terrettaz et al. (1995) found that the mean weight of individual berries increased by approximately 10% (from 18g to 21g) when 50% of the buds were removed. There were more severed buds in the unsprayed plots of the present study, and the berry size was expected to increase in response to the severing. Moreover, there were a higher number of *A. rubi* in the unsprayed plots. If *A. rubi* and other insects spread fungi, there should be more rotten berries in the unsprayed plots.

Totally, no considerably differences between sprayed and unsprayed plots in number of either rotten berries or big berries were revealed in fields of the same age. However, in some of the fields a higher proportion of rotten berries and/ or bigger berries was found in unsprayed plots. It has to be noted that these statements are not based on any statistical analyses.

On the yield

Even though the insecticides reduced the number of *A. rubi* and severed buds, this reduction was small considering dosage and number of insecticide application: The dosage of Gusathion permitted against *A. rubi*, is almost twice as big as the dosage allowed against apple fruit moth (*Argyresthia conjugella* Zell) (Anon. 2001). In addition, Gusathion is often applied twice to controll *A. rubi*, compared with only once against the apple fruit moth (N. Trandem pers. comm.).

The insecticides had a significant effect on the saleable yield, as well as on the weevil activity, but still no obvious relationship between the weevil activity and the total saleable yield could be found. I will give two examples that illustrate this: 1) In the first year field of grower A, sprayed plots had only 20% of the weevil number of unsprayed ones, but the difference in yield was only 4%. 2) In the third year field of grower B there were about twice as many severed buds as in the third year fields of grower A and C, but these differences were not reflected in the yield.

It is interesting to consider why the yield is lower in unsprayed fields. Several reasons can be suggested:

- There were *less weevils and less severed buds* in the sprayed plots.
- Insecticides gave a higher yield, by *reducing the number of rotten berries*, since a) weevils and/or other insects might spread the rot b) the sprayed plots are sprayed more often with fungicide, (when insecticides and fungicides were used in a mix).
- The insecticides might have *reduced the amount of other insects* that directly damaged the berries (e.g. capsids).
- The insecticides may have reduced the amount of other insects that influenced the yield indirectly. In unsprayed plots these insects (e.g. mites) could have weakened the plant, so it produced *fewer flower trusses*, had less ability to compensate and gave a lower yield.
- Maybe the insecticides had an *unknown positive effect* on the plants.

The reduction of weevils has some effect on the yield, since a relationship between the weevil activity and yield per flower truss was found. However, no clear relationship neither between the *A. rubi* caught and the total yield nor between the severed buds counted and the total yield was found, so the reduction of *A. rubi* and severed buds can not be the only reason for the effect of pesticides.

The proportion of rotten berries in sprayed and unsprayed plots was almost the same (see above). Therefore, the distribution of rotten berries cannot generally explain why the yield is lower in unsprayed plots. However, in fields where there tended to be were more rotten berries in the unsprayed plots, this can perhaps have been an additional effect of the insecticides or less fungicide spraying.

The presence of other insects than *A. rubi* had not been consistently registered during this fieldwork. But it is possible that insecticides had an effect by reducing the number of other insects that affected the yield either directly or indirectly. 'Cat faced' berries were not very widespread in these conventional fields. However, plants with two spotted spider-mites (*Tetranychus urticae*) were observed in the first year field of farmer A, and they probably weakened the plants and lowered the yield. Weakened plants might develop a lower number of berries, and they probably have fewer flower trusses. The present study showed that the number of flower trusses was very important in determining the yield (see above), especially in first year fields. The yield per flower truss in sprayed fields tended to be higher, but no significant effect of spraying was detected. The reason why a significant effect was found of spraying on the total yield, but not on the yield per flower truss can be that in the plants in the sprayed plots tended to have more flower trusses (but it was far from any significantly difference). Counting of flower trusses were conducted in the beginning of June (i.e.1-2 weeks after spraying). Thus, it is unlikely the spraying had great effect on the number of flower trusses counted. However, there might be a difference in the number of flower trusses and the number of berries that develop later in the season.

Differences between age classes.

As the plants grow older, the berries tend not to exploit their potential maximum size (Brandstveit 1978b). Thus, the third year plants might have greater ability to compensate than plants from first year fields by approaching the potential maximum size. The relationships between weevil activity and yield per flower truss, indicate that the ability to compensate was higher in the third year fields as well. On account of this, the effect of spraying was expected to be the highest in the first year fields, where the plants were smaller, had less ability to compensate and should be more vulnerable towards *A. rubi*.

However, in this study the effect of spraying was higher in third year than in first year fields. An explanation can be that the third year fields were more infested by weevils. Assuming the same proportion of *A. rubi* is killed independent of the age of the field, more weevils might have been killed in the fields with most weevils. Thus, the insecticides had a greater effect in third year than first year fields.

On the time of harvesting

For crops such as strawberry, where a premium price is paid for the first berries of the season, a delay in harvesting because of weevil damage could cause economic loss even if total yield was unaffected. An experiment (English-Loeb et al. 1999) revealed that removal of all primary buds resulted in slight delay in maturation (38% of fruit weight picked in the first harvest compared with 44% for control plots), but no effect of removing all the secondary buds on maturation was found. Removing of tertiary buds increased the proportion of fruit picked in the first harvest compared with control plots. Thus, damage of primary buds by strawberry bud weevil could result in economic losses (English-Loeb et al. 1999). Also another investigation showed that the severing of buds might cause a delay in the harvesting. The date when 10-50% of the yield was harvested was about 1-2 days late when buds (including the primary bud) had been removed (Cross & Burgess 1998).

The present study showed that the yield was higher in sprayed than unsprayed fields, but the proportion of berries harvested did not tend to be any earlier in sprayed fields (where there were less severed buds). There might still be a slight time lag, but this was not be apparent when the harvesting was done only three times a week. The strawberry bud weevil attacked buds of different orders, and this might be the reason why no effect on the time of harvesting was found. If predominantly primary buds had been attacked the results might have been different.

6.2.3. Overview over factors influencing the total yield

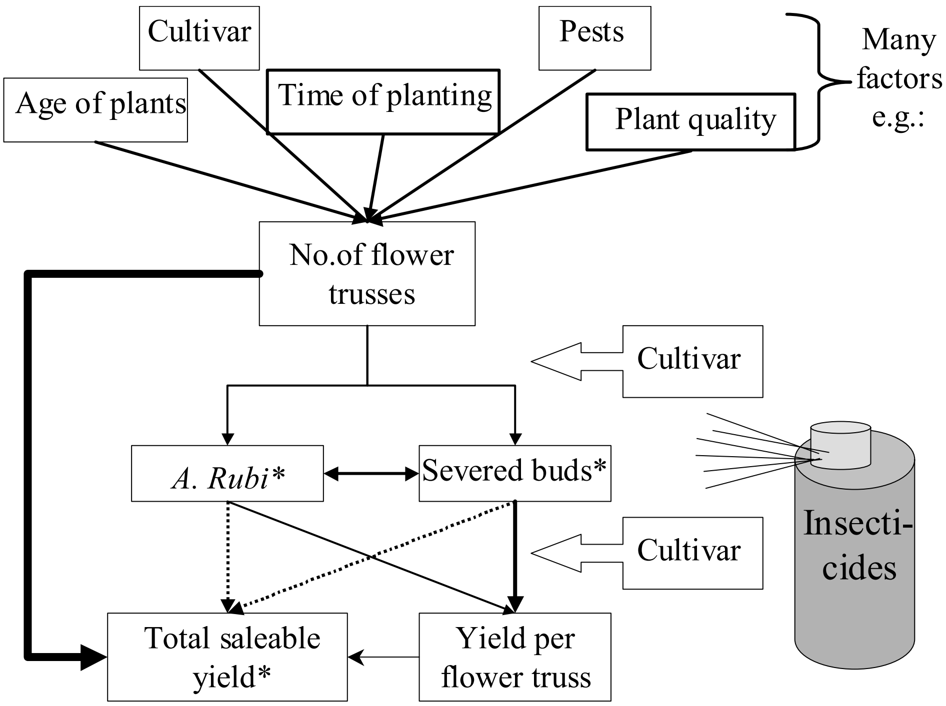


Figure 36: Conceptual model of factors influencing the total saleable yield in the present study. Heavy, thin and broken arrows depict strong, small and uncertain relationships respectively. *:Spraying has a statistically significant effect.

Many factors influence the number of flower trusses (Figure 36). The flowers are initiated in the autumn (Døving 1982), so the time of planting is important. In addition, the number of flower trusses increases with the age of the plant (Brandstveit 1978a and b, Meland 1985). Also insects can influence the number of flower trusses by weakening the plant.

With a higher number of flower trusses, the saleable yield increased. In addition, more *A. rubi* and severed buds were found. The increased number of *A. rubi* and severed buds decreased the yield per flower truss, but had no clear effect on the total saleable yield. Hence, the increased number of flower trusses weighed up for the additional severed buds.

Spraying significantly decreased the number of *A. rubi* and severed buds, while it significantly increased the total saleable yield and increased the yield per flower truss to some degree.

6.2.4. Differences between conventional and organic fields

The two methods of cultivation are difficult to compare because the fields were at different growers and in completely different districts in the south-east of Norway. The difference in the number of weevils could either be a result of the farming practices (both those that are required for organic growing, and individual differences, like use of plastic mulching), or a result of the climate and vegetation. In the organic fields, no insecticides (or other control methods) were used to regulate the weevil population, and one would expect to find most weevils. However, no differences between conventional and organic fields were detected, so the factor 'grower' was probably more important than the method of cultivation.

There tended to be more buds cut off per weevil in organic fields. Thus, the growth rate of *A. rubi* might be higher in organic field if enough buds are available. However, in year 2001 some registrations close to origo had great influence on the line, and this may have caused a steeper slope. Anyhow, it would be interesting to find out whether natural enemies and/ or intrasepecific competition would stabilize the population of *A. rubi*, or if the population continued to grow.

The highest number of severed buds per *A. rubi* was found in 'Korona'. Of this reason, the potential for population might be higher in this cultivar. The number of severed buds has to be seen in connection with the number of buds that were available, and the plants stage of development. Both the stage of development and the number of flower trusses are relatively similar for both 'Oda' and 'Korona' (Figure 37), so these two cultivars are probably the best to compare.

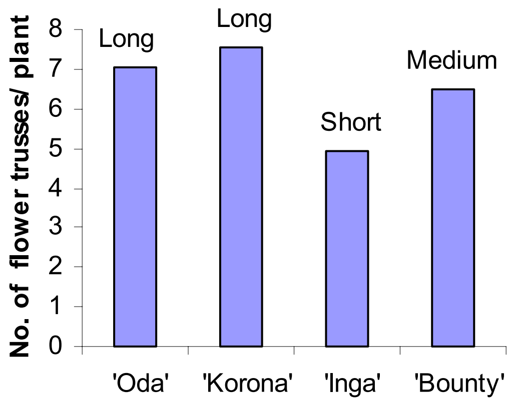


Figure 37: The average number of flower trusses (in different cultivars) in the plot where the severed bud registration was done. The plants' stage of development is divided into three groups according to how far the flower stalk had grown: short, medium and long.

If it is assumed that the weevils found on 23 May caused the severed buds counted a week later, a weevil in 'Korona' causes about five times more severed buds than a weevil in 'Oda'. Since 'Inga' was at a later stage of development and had in average fewer flower trusses per plant than the other cultivars, the percentage of buds damaged may have been just as high as for 'Oda'. The reasons for the differences in damage between different cultivars can be numerous, and these are discussed in the section Choice of cultivars. Whether 'Korona' is more vulnerable (i.e. has a higher yield loss) to *A. rubi* than the other cultivars, depends on the plants ability to compensate as well as the number of severed buds. Since the counting of severed buds and the beating registrations in the field of cultivars were done further apart (in the same double row), the relationship can have been weaker in the fields of cultivars compared with the 'Korona' fields.

When comparing conventional and ecological methods of cultivation, the fields should be of the same age, preferentially at the same farmer (using the same plant quality and planting methods) and have very similar edge vegetation. Otherwise the differences can be caused by other factors than the cultivation methods.

6.2.5. Practical consequences

Evaluation of the beating method

A high correlation between the number of *A. rubi* in the beating tray and severed buds counted was found in this study. Also Tuovinen and Parikka (1997) found such a correlation between beating tray registrations and the number of injured buds. Thus, this method has a potential to be used to predict the number of severed buds. Note that the relationship in this study was found using total numbers for the whole season.

The beating method has many advantages: First of all it is much quicker and easier to count *A. rubi* by beating than counting the severed buds. Furthermore, *A. rubi* can be found before any damage is done (i.e. before any severed buds are detected). Also other pest insects like capsids and some natural enemies can be held under surveillance (Tuovinen & Parikka 1997, pers. obs.).

The disadvantages are that the beating method depends on relatively nice weather, and cannot be used alone to predict the yield reduction. To be able to say anything about the possible effect on the yield, more factors have to be taken into account. Especially the number of flower trusses is important, but also how the development of *A. rubi* and the strawberry plant are synchronized. Early summer 2001, the plants in field G escaped some of the damage in time: Hardly any of the primary buds were attacked in this field, while very many of the primary buds were cut off at farmer F. If the weevil damages all the primary buds it might have greater economical consequences than if the buds of lower order are damaged. There might also be a problem that the damage might be irregularly distributed, and this will not be observed by beating registrations in just parts of the field.

The action threshold

The existing action threshold is based on the number of severed buds early in the season, so the relationship between the number of severed buds early in the season and the saleable yield is of particular interest. But the more severed buds found early in the season, the higher was the total saleable yield

The reason for this positive relationship might be that the plots with the highest number of severed buds early in the season contained plants of high quality and with many flower trusses. As a result, many severed buds early in the season did not negatively affect the yield. Another possible explanation is that these plots with many severed buds were at a later stage of development, so that more buds were available early in the season, and maybe the primary buds (which were the first to develop) were not severed because they escaped the damage in time.

If the beating method is going to be used to predict damage, the relationship between the early beating registrations and the total number of severed buds has to be examined. Or maybe beating in the autumn can give an indication of the damage the following year.

Control methods

At present use of insecticides is the only reliable control method, but other possible control methods will be discussed.

Insecticides

In third year fields the effect of insecticides was relatively high. But this effect is not satisfactory: many *A. rubi* and severed buds were detected in sprayed plots. Therefore we want to look for more effective control methods, with no/ few negative effects on the environment.

On the assumption that there were 5000 plants per daa and that one plant in sprayed fields yielded 0.2 kg, the yield would be 1000 kg/ daa. According to the present investigation, the yield reduction when not spraying in third year fields would be 24% i.e. 240 kg/ daa. Given a price of 20 NOK/kg, the economic loss would be 4800/ daa NOK. The costs of spraying once with Sumi-Alpha (50ml) and Gusathion (200g) were 21 NOK/ daa and 47 NOK/ daa respectively (Kråkevik1999). So it was definitely profitable to apply insecticides. However, it has to be taken in account that the insecticide applications might kill ‘beneficials’, so extra spraying might be necessary. In first year fields the effect of insecticides on the saleable yield was lower, a yield loss would be 60kg/ daa, (i.e.1200 NOK). It might be more important to concentrate on the plant quality and giving the plants a good start than to apply insecticides in first year fields. The yield is dependent on good and healthy plants, as well as correct production, planting and treatment after planting (Nes 1999). Some examples that illustrate the great effect different types of plants and time of planting have on the yield in ‘Korona’ follows (Nes 1999): In fields with and without plastic mulching, the yield of plants in their first year of production differed with 485kg/ daa and 140kg/ daa respectively, depending on how the plants had been produced. Too late planting reduced the yield dramatically as well.

More weevils are found in the edge especially in third year fields, early in the season i.e. at the time of insecticide application. This indicates that *A. rubi* damage can be reduced a lot by only treating the outside perimeter of the field. The plants near the edge vegetation are sometimes the weakest plants (fewer flower trusses), and thus not capable to compensate to the same degree as larger plants.

Choice of cultivars

The differences in susceptibility between cultivars have not been highly prioritised in this study. However, the few registrations from a field of cultivars indicated that there might be some differences in the number of severed buds between the cultivars.

According to the literature, cultivars of strawberry vary considerably in their susceptibility to *A. rubi* (e.g Simpsons et al. 1997, Höhn & Neuweiler 1993). Different reasons for these differences have been suggested. Cultivars with rich flowering (Blümel 1989) and a short and synchronic bud formation phase and a fast rate of bud burst (Popov 1985) are less affected. The diameter of the flower stalk (Blümel 1989, Popov 1985), the length of the flower stalk (Höhn & Neuweiler 1993 Popov 1996b) and the time of flowering (Jary 1932, Anon. 1950, Blümel 1989, Höhn & Neuweiler 1993 Simpson et al.1997, Labowska & Chlebowska 1999) are factors that have been examined. But the results from these investigations point in different directions. Simpson et al. (1997) discovered that cultivars were not equally affected, even though the flowering was synchronized. Thus, what some researchers thought was resistance to the strawberry blossom weevil, might just have been avoidance in time.

It has been suggested to grow non-pollen bearing varieties (Jary 1932). These varieties tend to show some degree of immunity since pollen grain represent a large proportion of the food of the adults and the early larval stages of *A. rubi*. (Jary 1932). But such cultivars are difficult to grow as some pollen-bearing plants are needed to obtain the required pollination and are not desired in Norwegian strawberry growing (F. Måge, pers. comm.). Furthermore, some eggs are deposited in such cultivars; consequently buds are cut off. The larva in such buds, fails to reach maturity (Jary 1932). Thus, the main effect will be apparent the year after.

Remove weevil and severed buds

Removing weevils or flower bud is only an alternative were labour or energy is cheap. The buds can either be removed by hand or by using suction device. Such a suction device can reduce the the number of severed buds by removing adult weevils (Hellqvist 1995). But the suction apparatus uses a lot of energy and removes natural enemies as well as pest insects (Hellqvist 1995). The effect of removing buds is probably relatively low: Most buds contain one egg (pers. obs) and at the most, one *A. rubi* develops from one bud (Lekic 1963). However, according to Popov (1996) only 1-5% survives the whole life cycle. Thus, a maximum of 5 of hundred buds that are removed from the field will develop into a weevil that causes any damage. On account of this, it will be more profitable to remove the adult weevils in the spring either by beating, with a suction device or catching them by using pheromones.

Covering the plants

None of the investigations where row covering had been tested showed exclusively positive results (Dalman et al. 1993, Mc Cue et al. 1993, Svensson 2000). In older fields *A. rubi* tended to do more damage when the fields were covered (Mc Cue et al.1993, Svensson 2000).

Biological control

Information concerning biological control of *A. rubi* is limited. A few control agents are known to control *A. rubi* (Jary 1931, Litnivov & Bodarenko 1987, Scanabissi & Arzone 1992), but there is little or no biological information on these parasitic species (Cross et al. 2001). In addition this type of control measure has not been successful in the fight against an *Anthonomus* weevil in America, the famous cotton boll weevil (*Anthonomus grandis*) in spite of decades of intensive research (Cross et al. 2001).

Pheromones

Research looking for pheromones as a control method has been done, with promising results (Cross et al 2000, Innocenzi et al 2001). Aggregation pheromones produced by the male *A. rubi*, which attract both females and males, have been found. Since the pheromones attract both females and male, it is more likely that the pheromones not only can be used in monitoring *A. rubi* but also for controlling it. However, more time is needed to develop trap devices, before the grower can use them.

6.3. Conclusion and further research

There were big differences from field to field in the number of *A. rubi* (found by beating), severed buds and yield. Weevil activity increased with the age of the field. The organic fields did not stand apart from the conventional fields in weevil activity or distribution of damage. There was a high correlation between the number of *A. rubi* and severed buds. Thus, the beating method proved to be promising in predicting the number of severed buds.

However, the relationship between the weevil activity and the yield per plant was uncertain. The number of *A. rubi* early in the season did not predict the yield loss alone. Neither is the existing threshold (10 severed buds/ 40 m. row before flowering) of any use in 'Korona', since the relationship between severed buds found early in the season and the yield was positive (in third year fields). With increased weevil activity, the yield per flower truss was reduced. As this effect was not detectable on the yield per plant, the number of flowers had probably more effect on the yield than the weevil. In first year fields over 70% of the variation in yield was explained by the number of flower trusses. To be able to predict the loss yield it would probably be ideal to count the percentage of severed buds, but this would be very time consuming.

Insecticides had a positive effect on the yield, especially in third year fields. In first year fields it might be better to spend money and time on improving the plant quality, than on insecticides. In fields of the same age there seemed to be no tendency of spraying affecting the time of harvest or amount of berries in the different yield categories.

Research has to be carried on in effort to develop a new action threshold in 'Korona', where the cultivar's ability to compensate for bud damage is incorporated. The beating method has shown to be a promising method to monitor weevil activity. However, the relationship between the early beating registrations and the total number of severed buds has to be examined more closely. Furthermore, several other factors have to be taken into account; especially plant age and synchronization between plant and pest. In addition, how the insecticides affect the yield should be studied further. Spraying might have an effect by reducing the number of *A. rubi,* but it might also affect other factors that not have been studied.

Development of pheromone traps and research to find cultivars that are less affected by the weevil will be important, especially in organic strawberry production. More knowledge concerning the weevils biology (hibernation sites, dependence on different edge vegetation and spreading ability) can be of great help in alternative control, and could also explain why some fields have much more *A. rubi* and severed buds than others.

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8. Appendices

Appendix 1: Photos from the different fields.

Appendix 2: Data registered per plot, total numbers for the whole sampling period, if nothing else is stated.

Appendix 3: Weevil, severed bud and yield registrations in the different plots (cf. Appendix 1) over time.

Appendix 4: Percentage of berries in the different yield categories at farmer A, B and C. The number at the top of each column indicates the total yield per 30 plants. N= 2 plots for each column.

APPENDIX 1:

Grower A, first and third year field.

Grower B, first year field.

Grower C, first and third year field.

Grower D, first year field

Grower E, third year field.

Grower F, organic field.

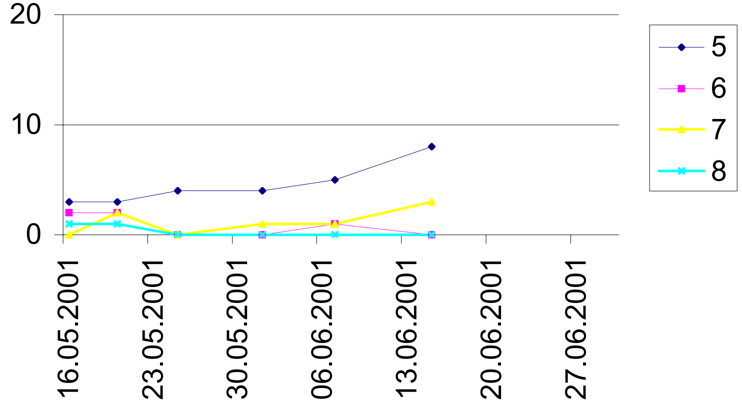
Grower G, field when spring litter was sampled, 29 April 2001.

Grower F, field of cultivars.

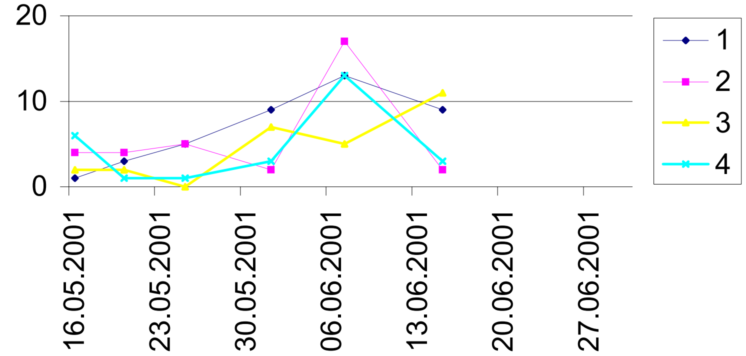
APPENDIX 2:

Plot No.	Grower:	Sprayed (1= sprayed):	Edge (1= edge):	No. of A. Rubi:	No. of severed buds: Total (left); in rows facing south/ west (middle); in rows facing north/ east (right).			Saleble yield (g.):	Total yield (g.):	Average No. of flower trusses/plant:	Saleable yield per flower truss (g.):
1	A	0	1	40	526	231	280	4821	6949	6.2	26
2	A	1	1	34	339	163	155	4922	8448	6.4	26
3	A	0	0	27	418	206	199	4291	6294	4.2	34
4	A	1	0	27	331	123	193	5702	9162	5.1	38
5	A	0	1	27	382	201	175	4668	6734	3.7	42
6	A	1	1	5	121	66	55	4812	6584	2.5	65
7	A	0	0	7	190	120	69	4524	6624	2.8	53
8	A	1	0	2	90	50	40	4734	7828	3.1	51
9	B	0	1	72	1176	624	473	4954	6221	8.6	19
10	B	1	1	50	968	474	414	6457	8275	8.6	25
11	B	0	0	55	1166	564	528	5513	8411	10.6	17
12	B	1	0	35	1084	603	414	8339	10975	9.6	29
13	B	0	1	21	588	286	300	3853	4320	3.0	43
14	B	1	1	28	442	209	233	4281	5085	3.2	44
15	B	0	0	31	428	187	241	5361	5656	3.3	54
16	B	1	0	25	481	191	290	5593	6818	3.7	51
17	D	0	0	14	325	138	183	-	-	8.6	-
18	D	1	0	19	356	158	178	-	-	8.5	-
19	D	0	0	6	342	139	194	-	-	8.5	-
20	D	1	0	5	258	138	113	-	-	7.3	-
21	D	0	1	16	223	106	105	-	-	2.9	-
22	D	1	1	7	247	111	104	-	-	2.7	-
23	D	0	0	11	252	174	73	-	-	3.2	-
24	D	1	0	6	170	114	42	-	-	3.0	-
25	E	0	0	27	618	297	297	-	-	10.2	-
26	E	1	0	18	641	335	291	-	-	10.9	-
27	C	0	1	27	474	205	248	6644	7253	7.7	29
28	C	1	1	13	336	163	134	8825	9897	10.1	29
29	C	0	0	29	713	303	396	7073	7894	7.8	30
30	C	1	0	5	408	175	201	9626	10849	8.4	38
31	C	0	1	16	261	161	100	8036	8373	4.7	57
32	C	1	1	7	195	79	116	9378	9663	4.1	77
33	C	0	1	7	248	144	104	9701	9831	4.5	71
34	C	1	0	7	109	48	61	9851	10197	4.5	72
35	F	0	1	31	637	329	291	2827	4475	5.1	18
36	F	0	0	25	844	379	450	2948	4164	5.6	18
37	F	0	0	28	688	359	318	2942	3810	5.1	19
38	F	0	0	16	843	448	391	2610	4033	5.4	16
39	F	0	1	29	765	346	418	2418	3936	5.6	14
40	G	0	0	5	70	39	26	-	-	3.1	-
41	G	0	0	4	100	28	59	-	-	3.5	-
42	G	0	0	8	144	63	66	-	-	2.6	-
43	G	0	0	2	84	37	31	-	-	3.3	-
44	G	0	1	15	322	154	140	-	-	2.2	-
45	G	0	1	5	169	64	88	-	-	2.7	-

Grower A, first year, weevil registrations.



Grower A, third year, weevil registrations.



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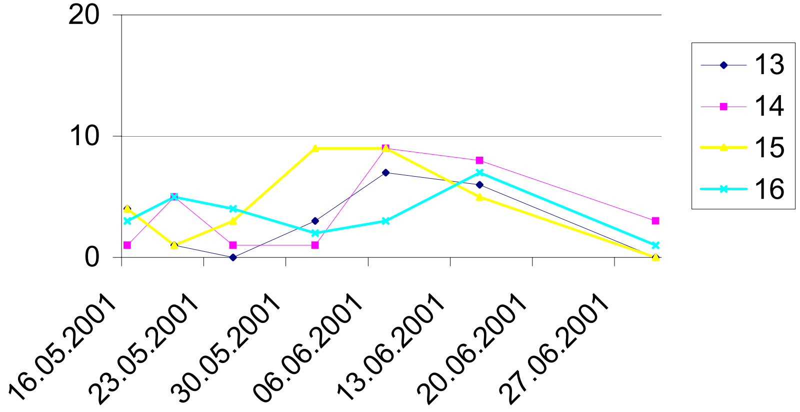

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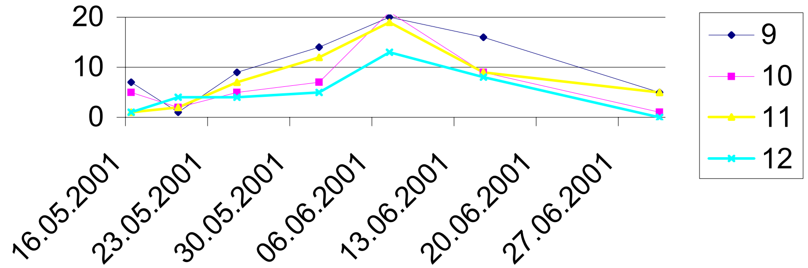

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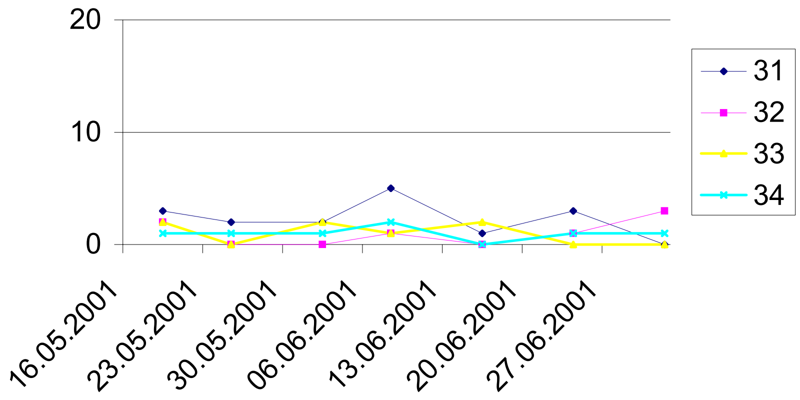

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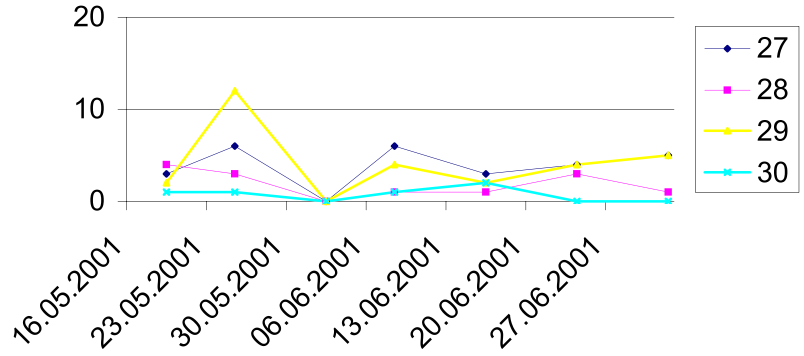

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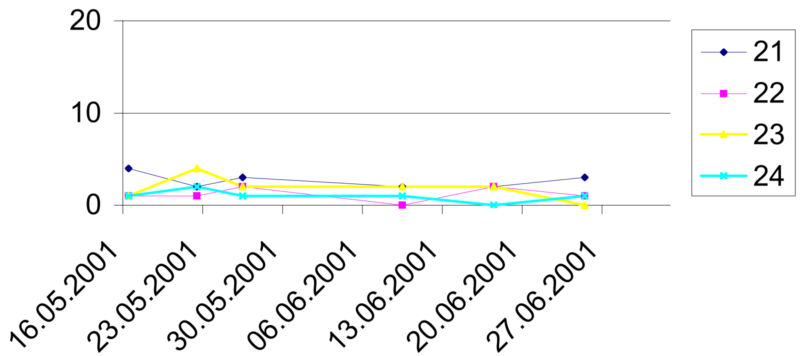

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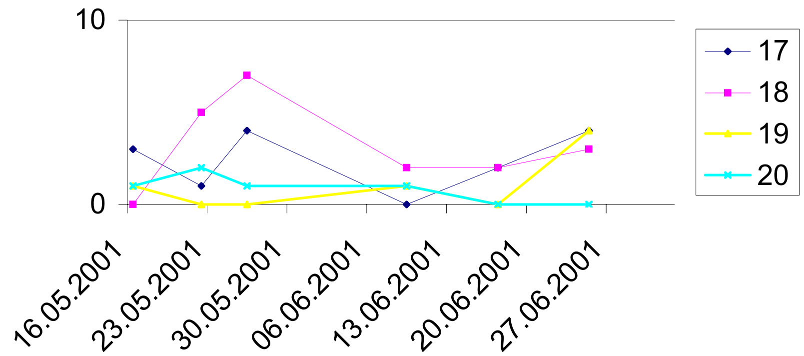

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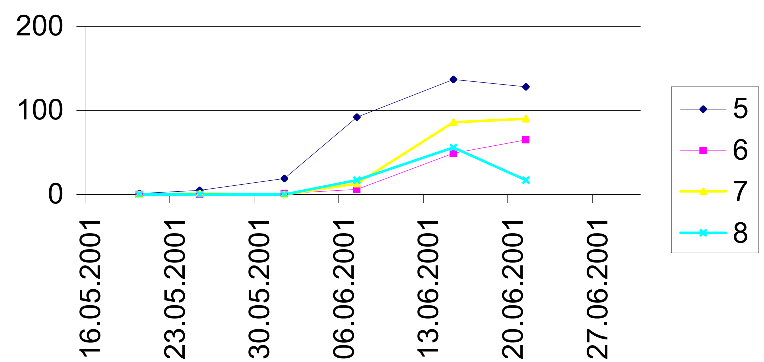

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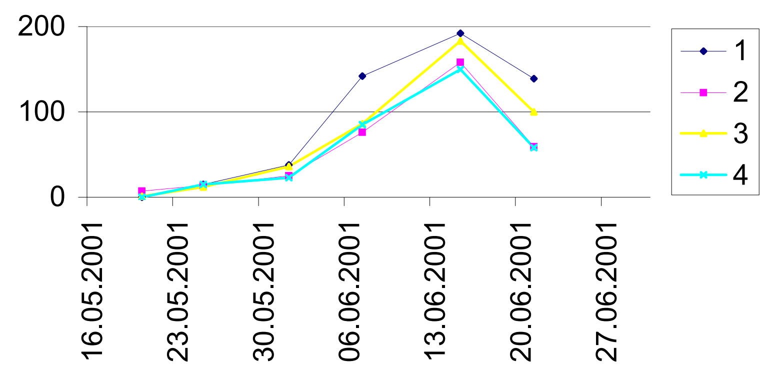

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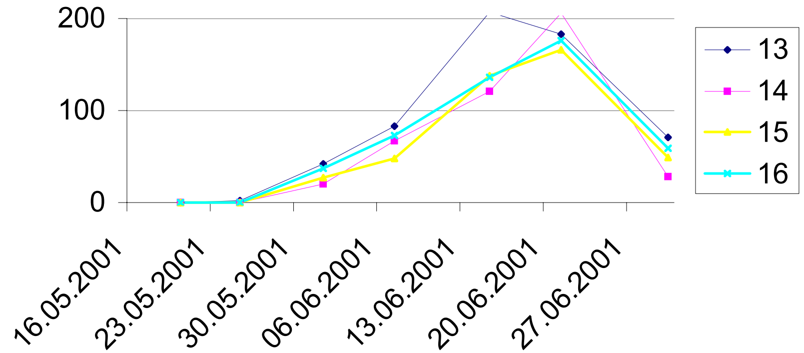

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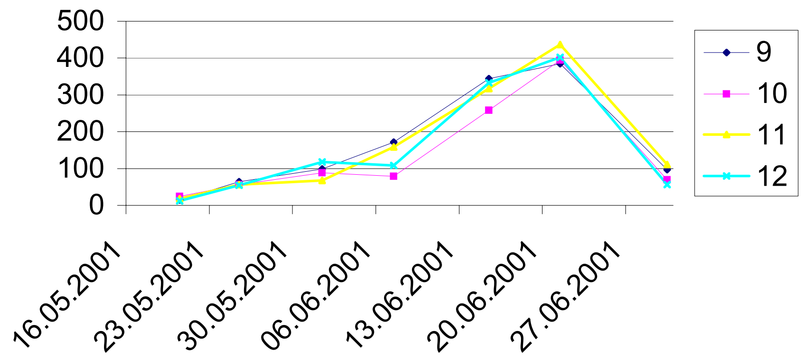

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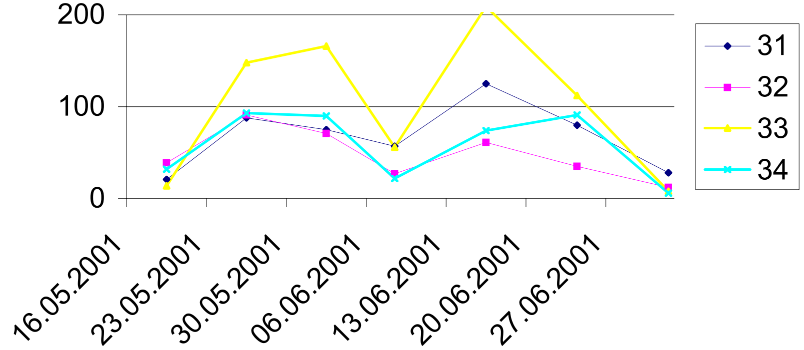

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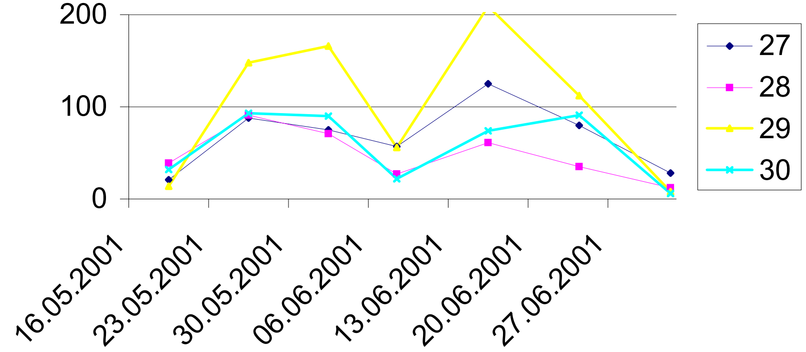

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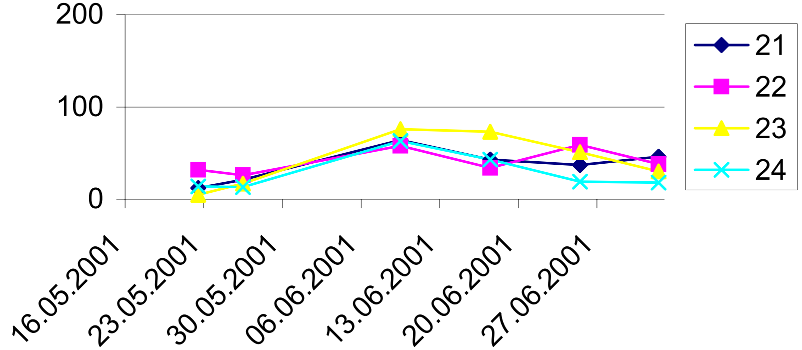

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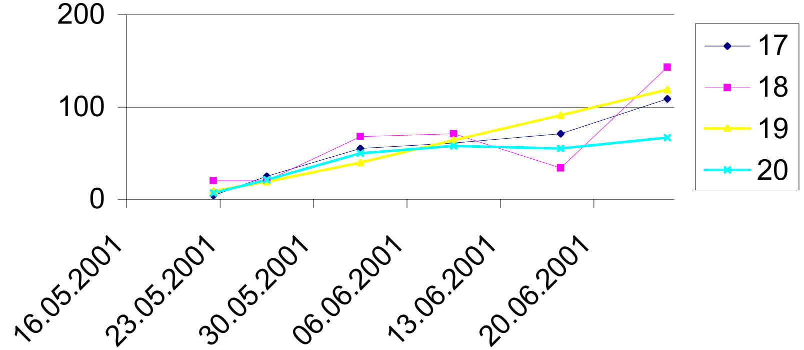

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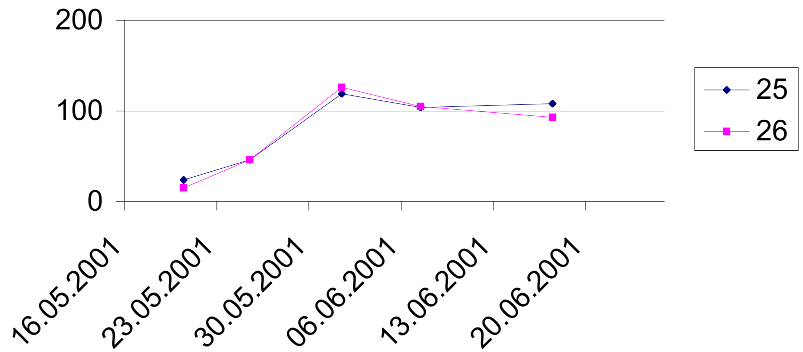
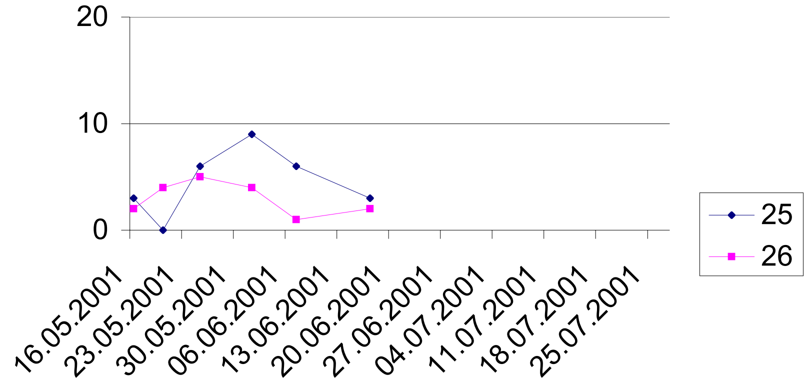


Grower E, third year, weevil registrations.



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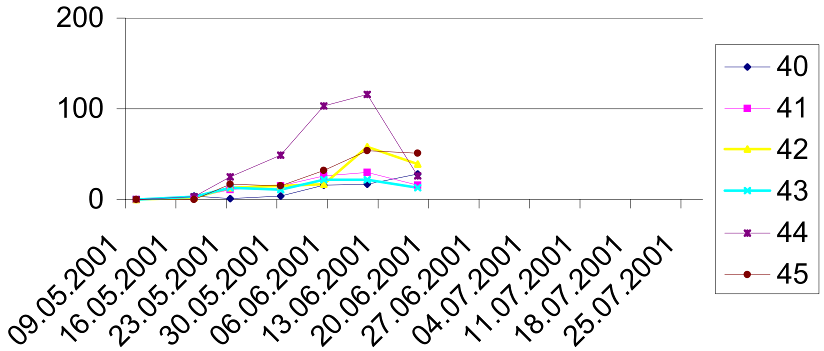

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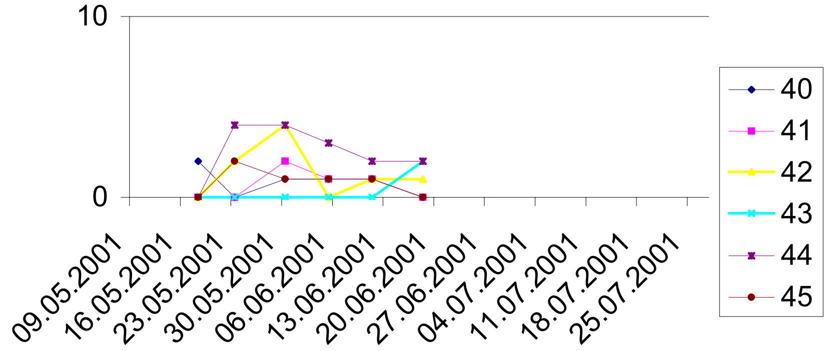

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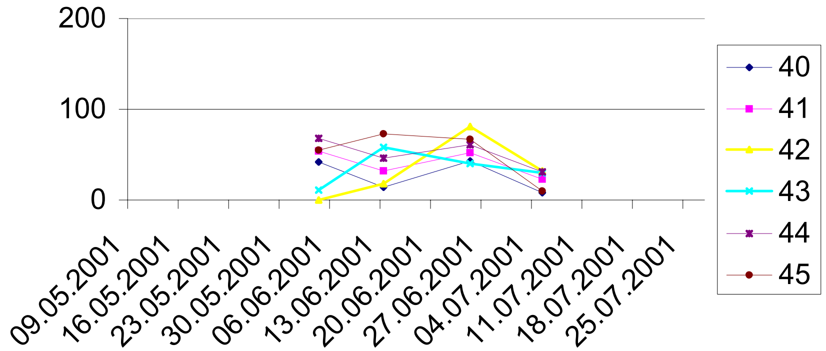

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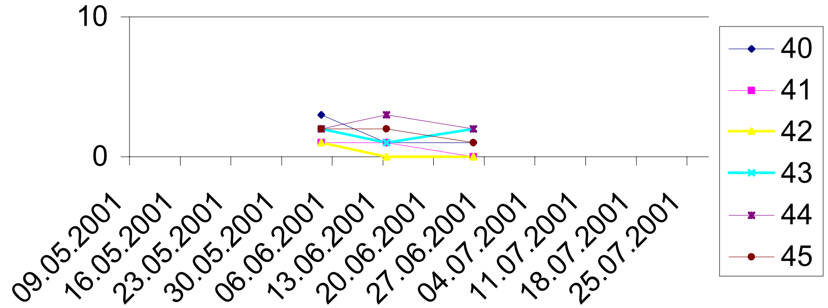

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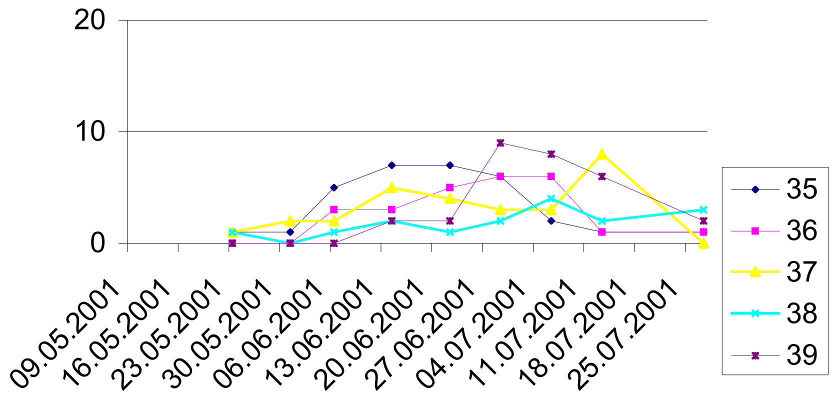

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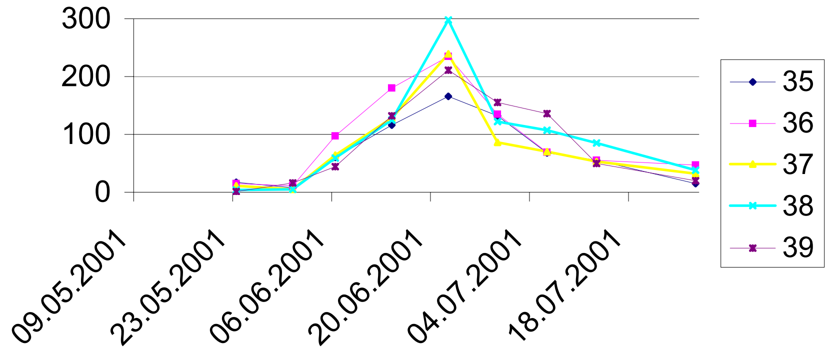

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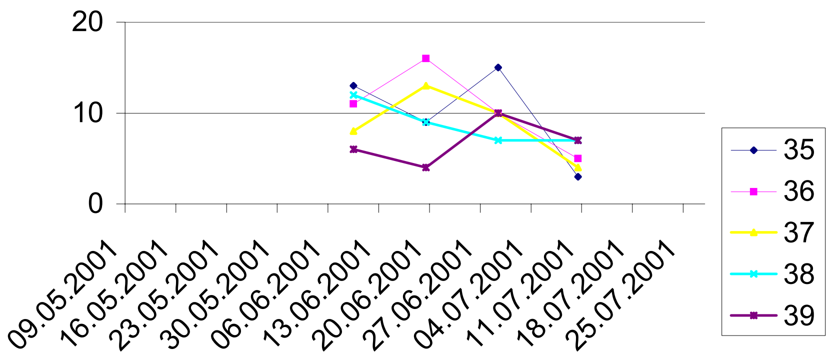
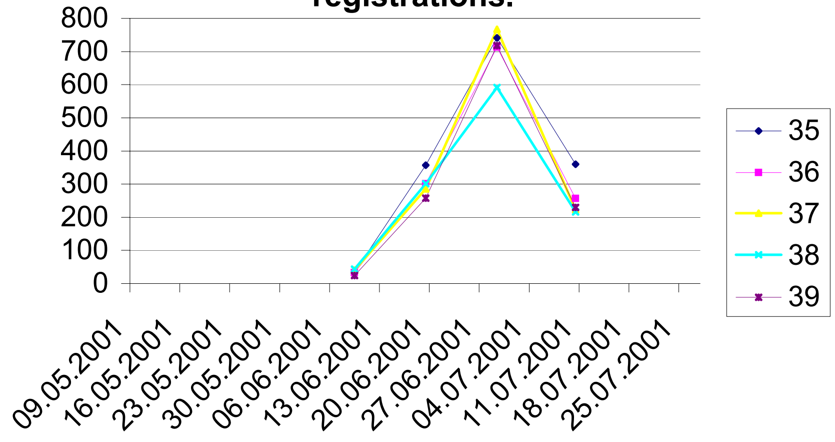
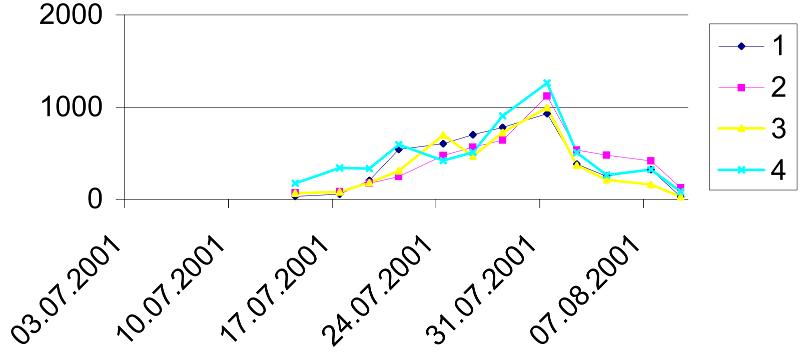


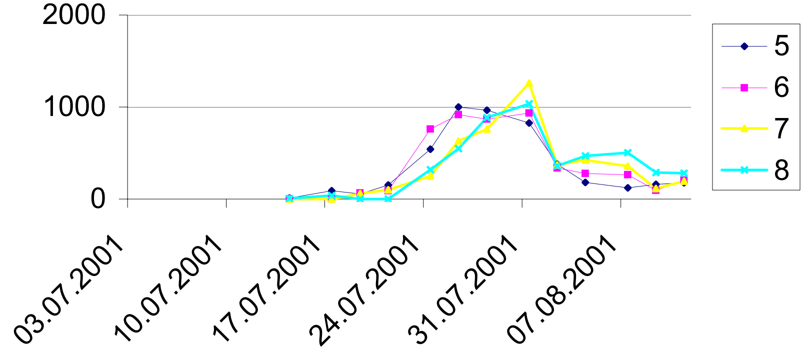
Grower F, second year, severed buds registrations.



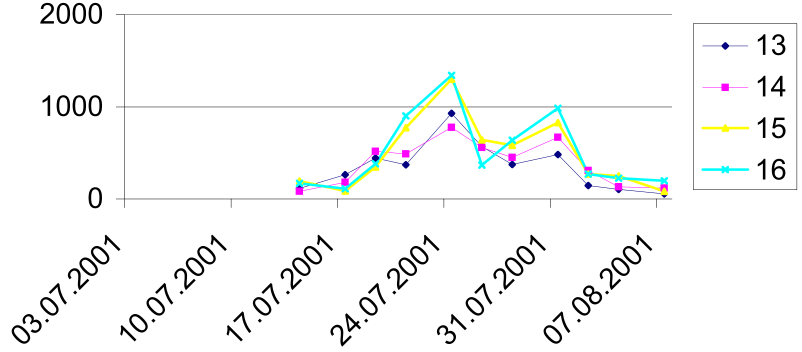
Grower A, first year, saleable yield over time



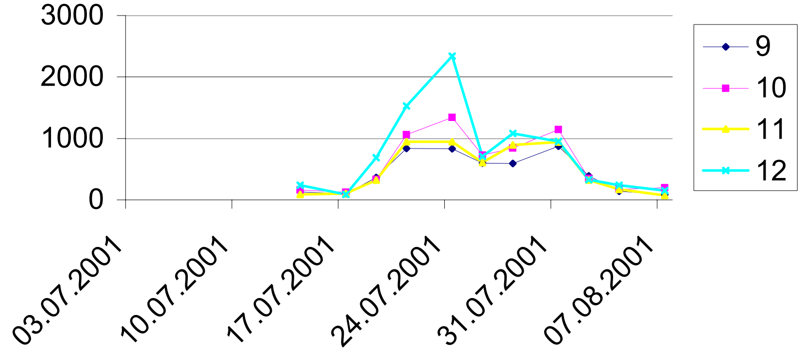
Grower A, third year saleable yield over time



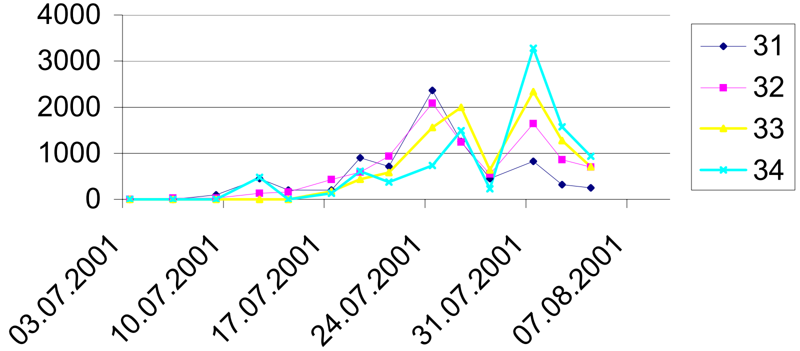
Grower B, first year saleable yield over time



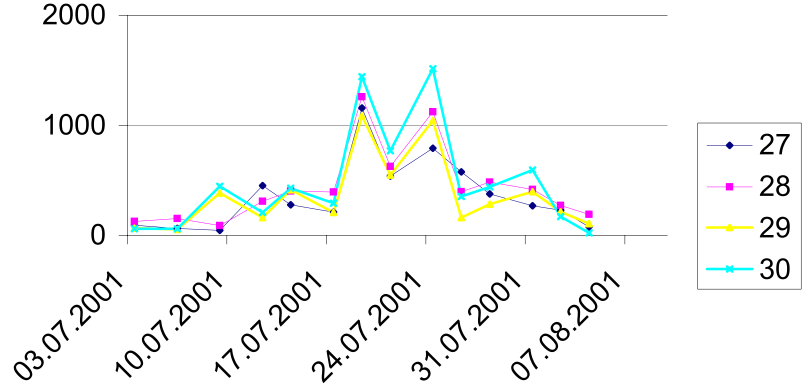
Grower B, third year, saleable yield over time



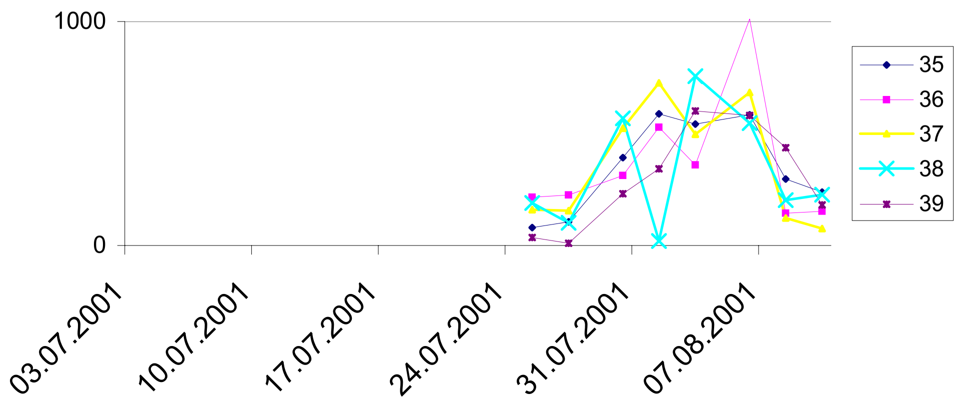
Grower C, first year saleable yield over time



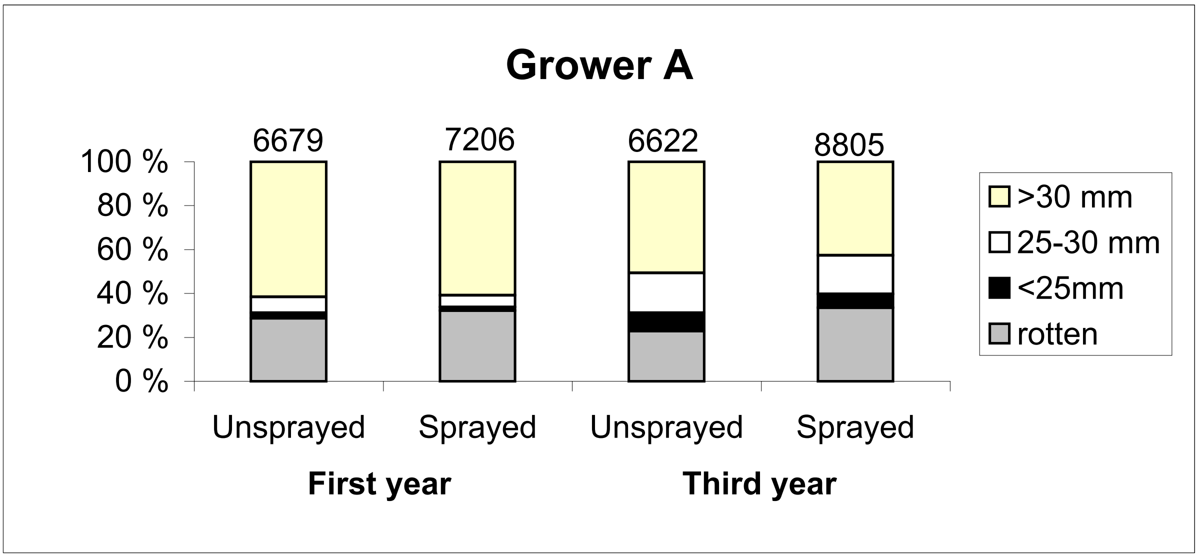
Grower C, third year, saleable yield over time



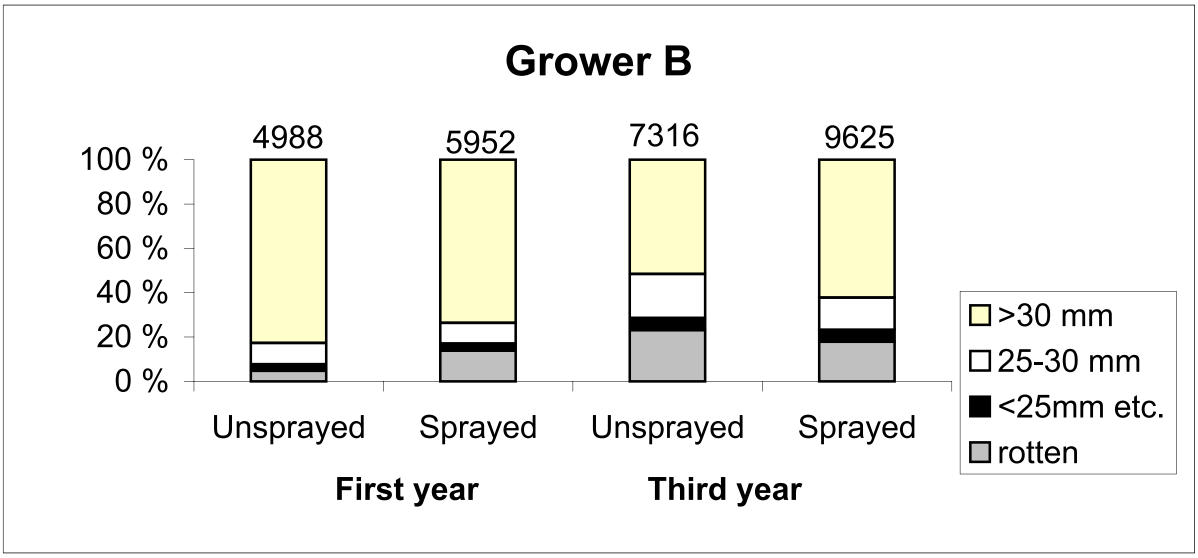
Grower F, first year saleable yield over time



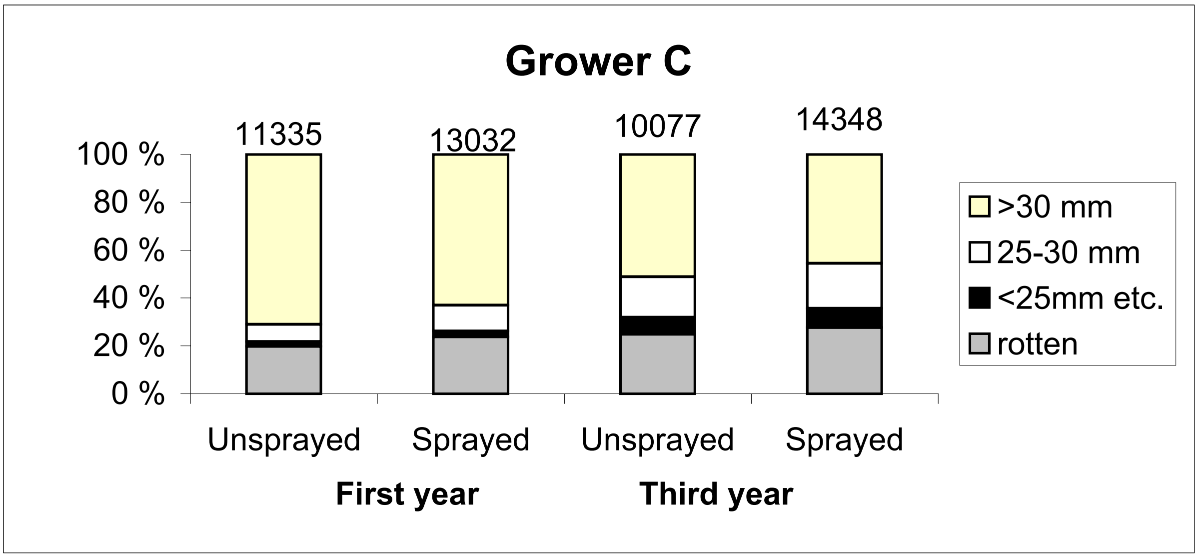
APPENDIX 4:



Grower A
6679
7206
6622
8805
100 %
80 %
60 %
40 %
20 %
0 %
>30 mm
25-30 mm
<25mm
rotten
Unsprayed
Sprayed
Unsprayed
Sprayed
First year
Third year



Grower B
4988
5952
7316
9625
100 %
80 %
60 %
40 %
20 %
0 %
>30 mm
25-30 mm
<25mm etc.
rotten
Unsprayed
Sprayed
Unsprayed
Sprayed
First year
Third year



Grower C
11335
13032
10077
14348
100 %
80 %
60 %
40 %
20 %
0 %
>30 mm
25-30 mm
<25mm etc.
rotten
Unsprayed
Sprayed
Unsprayed
Sprayed
First year
Third year