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The Impact of the Strawberry Bud Weevil (*Anthonomus signatus*) on Raspberry (*Rubus idaeus*) in Maine

Christina S. Howard

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**THE IMPACT OF THE STRAWBERRY BUD WEEVIL (*ANTHONOMUS
SIGNATUS*) ON RASPBERRY (*RUBUS IDAEUS*) IN MAINE**

By

Christina S. Howard

B.S. University of Maine, 2003

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Plant, Soil and Environmental Science)

The Graduate School

The University of Maine

August, 2007

Advisory Committee:

Renaë Moran, Associate Professor of Pomology, Co-advisor

David Handley, Cooperating Professor of Horticulture and Small Fruit and
Vegetable Specialist, Co-advisor

Mark Hutton, Associate Professor of Vegetable Crops and Extension Vegetable
Specialist

James Dill, Extension Associate Program Administrator, Pest Management:
Extension Professor: Cooperating Professor

Frank Drummond, Professor of Insect Ecology/Entomology: IPM Coordinator

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than primary buds were removed, size of fruits from primary flower buds increased slightly for 'Encore' but not nearly enough to compensate for the loss of yield compared to the control (no buds removed).

Flower bud clipping treatments in a field experiment were not characterized by any significant impact on yield in 'Reveille' raspberry. Up to 31% of the flower buds were removed from canes without significantly affecting fruit weight, fruit number or fruit size. However, wide variation within treatments as a result of environmental factors, including winter injury and shading, seemed to have more of an impact on the treatments than clipping buds. Also, the buds were all clipped on the same day, which is not representative of actual SBW damage in the field and may, therefore, not have produced a response characteristic to SBW damage.

In two sequential field surveys of fourteen commercial raspberry fields in Maine, up to 22% and 59% damage to flower buds was found in 2005 and 2006, respectively. Flower buds on raspberry plants were concentrated near the base of the cane, whereas damage caused by SBW was distributed over the canes; there was more damage present where there were more buds. The data suggests that SBW is an important pest in raspberries in Maine.

The most effective scouting method for estimating actual bud damage in the field was visual estimates of clipped buds. Other scouting methods, such as the sticky traps, pheromone traps, sweep nets and beat cloths to monitor live clipper, were not effective at predicting actual bud damage. These studies have shown the need for development of effective monitoring methods for SBW in raspberry fields in Maine, and a better understanding of the ability of the raspberry plants to compensate for bud damage.

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INTRODUCTION AND OBJECTIVES

The red raspberry (*Rubus idaeus* Linné) is a high value commercial crop on many small farms in the northeastern United States. Flower buds of this plant are known to be attacked by the strawberry bud weevil (SBW), *Anthonomus signatus* Say, a well-recognized pest of strawberries (Bostanian *et al.*, 1999; Easterbrook *et al.*, 2003; Khanizadeh *et al.*, 1992; Kovach, 1995; Kovach *et al.*, 1999; Mailloux, 1993; and Pritts *et al.*, 1999), but its economic impact on raspberry is unknown. SBW is more commonly known as “clipper,” because of the females’ behavior of laying their eggs in flower buds and then severing, or “clipping,” the bud from the plant (Pritts *et al.*, 1999).

Fruit yield compensation in response to clipped flower buds has been found in strawberry plants, and may provide a means for plants to tolerate clipping injury with little to no impact on yield. Strawberries compensate for flower bud loss by producing additional high order buds that result in a greater number of fruit per plant. This ability to compensate decreases when clipping occurs at a later stage of bud development (Pritts *et al.*, 1999). It has been shown that raspberry plants can compensate for the loss of lateral shoot buds or primocanes (Moore, 1994), but, if the damage occurs during the dormant or early stages of growth, it is not known if the plants can compensate for the loss of flower buds, as occurs under a SBW infestation.

Observations by several entomologists (J. Dill, A. Eaton, D. Handley and S. Schloemann) in the region have suggested that SBW may be responsible for raspberry flower bud losses approaching 75% in New England. Yet few growers recognize the problem because the damage occurs early in the season, prior to typical pesticide applications. If raspberries are a preferred host for SBW and flower bud losses resulting

from its activity are high, this insect could be causing significant economic damage to commercial raspberry crops. A more complete picture regarding the activity of SBW on raspberry and its impact of raspberry fruit development could help farmers decide when, and if management efforts for this insect are needed to prevent significant crop losses.

The specific research objectives are as follows:

1. To evaluate the yield compensation potential of two raspberry varieties subjected to various levels of manual flower bud removal as experienced under field conditions when exposed to SBW.
2. To evaluate the effect of various levels of flower bud removal on subsequent yield and fruit characteristics of 'Reveille' raspberry, as might be experienced under field conditions when exposed to SBW.
3. To evaluate the efficacy of several different monitoring methods to assess population levels and distribution of SBW in Maine raspberry plantings.
4. To determine the correlation between monitoring methods and actual raspberry flower bud damage caused by SBW.

LITERATURE REVIEW

The Raspberry Plant (*Rubus idaeus*)

The raspberry plant belongs to the family Rosaceae, the genus *Rubus* and species *idaeus*. *Rubus* plants are characterized by flowers with five petals and the production of aggregate fruit, consisting of many drupes, each drupe surrounding one seed, around one receptacle. Raspberry plants have perennial roots and biennial shoots, or canes. The shoots produce fruit in the cane's second year of development and then expire (Crandall, 1995).

Raspberry plants are shallow-rooted, with approximately 75% of the root system spread out laterally in the upper 0.45 m of soil. The remainder of the roots may extend down 1.8 m in well drained soil. The roots range in size up to 1.2 cm in diameter and may have vegetative buds unevenly spaced along them. From these root buds, raspberry shoots develop. These shoots, or canes, are biennial and are called 'primocanes' during their first year of vegetative development. After emerging from buds on the roots, these primocanes typically grow as a single stem, reaching 0.5 to 1.5 m in height (Crandall, 1995). Along the stem, tri-foliolate leaves emerge in a spiral pattern from the apical meristem. Axillary buds develop at each leaf axil along the cane. These buds initiate flower primordia under appropriate environmental stimuli, primarily shortened daylength and decreasing temperatures, in the fall (Crandall, 1995). After flower initiation, the canes stop growing and enter dormancy. In Maine, raspberry cultivars need to experience a chilling period for continued growth in the next growing season. This chilling period varies in temperature from 7°C to -29°C, and a chilling duration from 250-1400 hours depending on the cultivar. The canes break their dormancy period after they have fulfilled

the number of hours needed in chilling and when temperatures warm up enough for continued growth. Once the cane stops growing vegetatively and starts reproductive growth, the canes are then called floricanes, the reproductive state of the plant (Crandall, 1995).

After the chilling period, under suitable environmental conditions, the lateral buds at each leaf axil on the floricanes respond to increasing temperatures and daylength by elongating and forming usually one fruiting lateral per leaf axil. A fruiting lateral is a shoot with the ability to produce an inflorescence arising from an auxiliary bud. The laterals develop bracts, leaves, and flowers (Crandall, 1995).

Each fruiting lateral has the potential to produce a fruiting cluster consisting of primary berry at the terminal end of the lateral and two to four secondary berries just below the primary berry. Together these make up the terminal cluster. Below the terminal cluster are many smaller secondary buds stemming from auxiliary nodes on the fruiting lateral. These may form individual fruit below the terminal cluster. Branching from each of these secondary berries' stems may or may not be a tertiary berry. This branching lateral flower structure is referred to as a racemose inflorescence, where the 3-5 flowers, the terminal cluster, are born terminally and other buds are formed laterally on individual stems along a central axis. Following fruiting, floricanes senesce, sending much of their carbohydrate reserve back to the root system and, at the end of the season, the floricanes expire (Crandall, 1995; Fernandez and Pritts, 1993; and Logsdon, 1974).

Raspberry Reproduction

Raspberry flower initiation is affected by environmental conditions, cultural practices and cultivar differences. The timing of flower initiation is determined by plant vigor, the intensity of light the plant receives, day length and air temperature (Oliveira *et al.*, 2004). Oliveira *et al.* (2004) found that the intensity of light each cane receives in the field is the most important environmental factor affecting the flower initiation of the raspberry plant.

Individual raspberry flowers have thin, long stems, five sepals, five petals and numerous stamens and pistils seated on a fleshy receptacle. The stamens are located at the base of the receptacle, the end of the pedicle, in two whorls. Approximately 150 pistils, depending on the cultivar, are arranged spirally above the stamens on the elongated part of the receptacle. After pollination the base of each pistil enlarges to form two ovaries, which can produce two seeds, only one of which will develop. As the seed develops it will form a hard seed coat (the endocarp), then a cover of flesh (the mesocarp) and skin (the exocarp). This all together forms a peach-like structure called a drupe. Each drupe is a complete fruit and is a sink for resources from the plant. Approximately 100 drupes, depending on the cultivar and pollination, are held on the receptacle by vascular bundles and to each other by epidermal hair entanglement to form one aggregate, or raspberry (Robbins *et al.*, 1988).

Fruit set describes the mechanisms that allow the plant to reproduce and the amount of fruit the plant produces. Raspberry fruit set is affected by many factors including light penetration, cane height, cultural practices (such as pruning and cultivating), nitrogen levels in the plant and in the soil, carbon reserves in the roots,

health of the foliage, regularity of the cooling period, the cultivar differences, diseases, water, and pollination (Crandall, 1995; Vanden Heuvel *et al.*, 2000; Wright and Waister, 1984). Cultural management of the crop, such as accurate fertilizing, planting in the correct soil and sufficient pruning, all play a part in the productivity of the raspberry crop (Schloemann *et al.*, 2000). Pollination and presence of disease are among the most important aspects of fruit set considering that to ensure individual seed development for each drupe of each berry, each pistil needs to be pollinated (USDA, 1976). Raspberry flowers may have up to 150 pistils, but the average raspberry has approximately 100 drupes, therefore, 100 seeds. Since not all of the anthers and not all of the stigmas are open and receptive at the same time, pollinators must make repeated trips to each flower to ensure sufficient pollination for each flower (USDA, 1976). Raspberries are also self-fertile, although are much less prolific if left to fertilize themselves (Fernandez *et al.*, 1998). The lack of pollination and disease control, primarily viruses, has a direct result of “crumbly berries” (berries with only a few number of drupes) (Daubeny *et al.*, 1970; Jennings, 1967; Redalen, 1976). Other factors affecting fruit set in raspberries include nitrogen levels in the plant and in the soil, health of the foliage, light conditions, regularity of the cooling period, and cultivar differences. Cultural management of the crop, such as nutrition, soil management, cultural practices and pest management play a part in the productivity of the raspberry crop (Schloemann *et al.*, 2000).

Commercial Production – New England

Red raspberries have the potential to be a high-value crop, but they can be challenging fruit to grow in New England (Schloemann *et al.*, 2000). The ripe fruit is soft and perishable, therefore, the fresh marketing time is very short. The fruit is highly

susceptible to many insect pests and diseases during development. Further, raspberry crops require a high amount of labor for pruning, trellising and harvesting. However, the red raspberry industry in New England is distributed throughout all six states and is worth \$2,428,737 (Keough, 2006). Maine raspberry production represents 25% of the total production for New England with 140 farms producing raspberries 0.75 acres on average per farm (Keough, 2006). On average, farms in New England are producing 1725 pounds per acre and are selling fresh market raspberries at \$3.32 per pound (Keough, 2006). The average Maine farm between 2002 and 2005 made \$4,244 per year for their 0.75 acre of fresh raspberry production. Maine's raspberry crop is sold at farm stands, supermarkets and U-Pick businesses (Keough, 2006).

The Strawberry Bud Weevil (SBW)

The strawberry bud weevil is in the family Curculionidae, genus *Anthonomus*, species *signatus* Say. The adult clipper is one eighth of an inch long with a copper back with white stripes, a black head with a long snout and four legs. SBW overwinter in strawberry or raspberry field soil, or in the soil under bushes, weeds or woods near the field. It is not clear if SBW are native to Maine. The adults become active in early spring, coinciding with raspberry and strawberry bud development (Mailloux and Bostainian, 1993). SBW are generalists and use many different types of plants for feeding and oviposition. The host plant bloom period must coincide with the SBW feeding, mating and oviposition. SBW eat the pollen of the host plants. In Maine, host plants include cultivated strawberry and raspberry plants, wild brambles and strawberries and other wild plants that exist along the edges of fields (Schloemann *et al.*, 2000). Aggregation pheromones help the insects identify food sources and encourage mating. There is

approximately a 1:1 ratio of male to female SBW in the field (Mailloux and Bostainian, 1993). The female SBW finds a bud of approximately 5mm in diameter, punctures the base of the bud and inserts a single egg into the bud, then girdles the pedicel with her mouthparts (Spangler *et al.*, 1988). The girdled bud dries up and falls to the ground beneath the plant (Mailloux and Bostainian, 1993). The egg hatches and larvae feeds on the excised bud. The larval is about 2mm in length and is yellowish-white and mottled with black. It develops and pupates inside the bud. The pupae is creamy white and sometime mottled with black. The SBW pupates and emerges as an adult in about ten days (Spangler, 1988). SBW has only one generation per season and each adult female can lay up to 75 eggs (Pritts *et al.*, 1999).

On strawberry, SBW damage can vary significantly from year to year, thus field scouting is often used to determine when, and if, the economic injury level for this insect has been reached (Mailloux and Bostainian, 1993). To scout for SBW on strawberry, flower buds are examined weekly once the plant has visible flower clusters. The scout looks for clipped buds and live SBW, which may hide in the unexpanded flower clusters, especially in cold weather. Scouting two-foot sections of plant row for clipped buds in five to ten sites in each one-acre field can accurately predict SBW population levels in a field. The economic threshold for SBW in strawberry crops is three, highly damaged flower clusters per row-foot or one live SBW (Schloemann *et al.*, 2000). If part of the field is near wooded areas, additional scouting along that edge of the field is usually necessary since field edges are the likely source of overwintering SBW (Pritts *et al.*, 1998). In fact, a spray along the side of a field that borders woods may be sufficient to control SBW (Schloemann *et al.*, 2000).

Innocenzi *et al.* (2001) identified an aggregation pheromone for a European species of strawberry weevil, *Anthonomus rubi*. Its two main components are identical to the pheromone components in the boll weevil, *Anthonomus grandis*, pheromone: grandlure II and grandlure I. Traces of two other pheromone components, grandlure III and IV, in the *A. grandis* pheromone were also detected in the male *A. rubi* pheromone. In their study of the European SBW pheromone, Innocenzi *et al.* (2001) found that sticky traps baited with male pheromone and hung in the field caught more females than males in the middle of the season and more males than females later in the season. This pheromone has not been tested on *A. signatus* for effectiveness in Maine.

Although raspberries have been cited as a host for SBW (Schloemann *et al.*, 2000), there has been very little work to determine its potential economic impact on this crop and scouting techniques and thresholds have not yet been developed. Observations by several entomologists in New England have suggested that clipper may be responsible for flower bud losses approaching 75%. Preliminary studies done at the University of Maine show 5% to 55% injury levels in raspberries based on bud counts (Handley, 2004 unpublished data). Strawberry bud weevil damage occurs in late spring, often before conventional raspberry pest management efforts begin (Schloemann *et al.*, 2000). As a result, few growers recognize the problem and have strategies to monitor or control it.

Raspberry Plant Compensation and Source-Sink Relationships

Identifying the source/sink relationship between the orders of raspberry flower buds and nutrient sources, including the direction of nutrient flow when sinks are removed, is important for understanding the effect of flower bud loss due to SBW on the development of the remaining raspberry fruit.

Most raspberries have a biennial habit, in which canes grow vegetatively the first year, initiate flower buds in the fall, then set fruit during the second year followed by rapid senescence. Raspberry plants initiate flower buds in response to shortening days, lowering temperatures, and light intensity (Moore and Caldwell, 1985).

A reduction in carbon supply in the current year does not necessarily affect the current year's crop yield. Raspberry plants can shift carbon allocation among fruits and other parts of the plant when carbon sinks are changed in some way, such as removal of canes or laterals on each cane (Fernandez and Pritts, 1996). Fernandez and Pritts (1996) suggest that raspberry roots are very strong carbon sinks, and that raspberry plants may use the stored carbon from the roots when the current photosynthate production is low. Moore *et al.* (1985) described another source/sink relationship among canes, where, under very thick cane stands (more canes per meter than the control), the "fruitfulness per cane" was decreased because of competition for nutrients and light. Waister *et al.* (1977) looked at the interaction between primocanes and floricanes in red raspberry cultivars in Scotland, UK and Oregon, US, and found there is competition for resources between the two different developmental stages at the time of floricanes fruiting, showing a decreased yield when primocanes were present. Conversely, Fernandez and Pritts (1993) looked at carbon assimilation and partitioning of the raspberry developmental stages and found that the two developmental stages did not seem to be sharing fixed carbon products during fruiting. They found that primocanes increased dry matter linearly until floricanes were in peak harvest. During harvest, primocanes stopped growing. After harvest the primocane dry matter increased linearly again. Floricanes increased dry weight steadily up to full bloom and then leveled off. The raspberry roots have an initial loss of dry weight during

bud break in the floricanes which coincides with the emergence of primocanes.

Fernandez and Pritts (1993) concluded that the roots are competing with the primocanes for carbon assimilates. During fruiting, the roots out-compete primocanes for those resources and send them up to the floricanes. Waister *et al.* (1977) found that this source-sink relationship continues into the flowers.

A simple method to evaluate source/sink relationships is to remove a sink and see if and where the plant reallocates the resources and compensates for the loss of that sink. The removal of canes from the raspberry plant has demonstrated compensation in two different studies. Crandall *et al.* (1980) suppressed primocane growth with dinoseb applications and found that plant yields increased by up to 70% as compared to untreated plots. With re-treatment of these same plots over four years the yield increase was maintained. Most of the yield increase was attributed to a greater number of berries on the lower and middle laterals, not the top laterals. Berry size increased in only a few cases. Freeman *et al.* (1989) looked at the same chemical application to suppress primocanes and found the sprayed plots had fewer floricanes, larger fruit and increased yield. It is hypothesized in both of these studies that the mechanism for compensating yield is removal of a resource sink with the primocane removal, therefore, allowing the extra resources to be used in fruit production by the plant. However, removal of primocanes also allowed floricanes to have better photosynthetic efficiency and less shading of lower buds, resulting in higher yields of lower laterals.

Moore (1994) examined the ability of raspberry plants to compensate for loss of lateral buds. He found that yields of eleven different varieties were equal to the control plots despite the removal of up to 50% of lateral buds when the canes were dormant. The

plants appear able to compensate for the loss of lateral buds by stimulating secondary buds to break and produce replacement laterals. Braun and Garth (1984) also tested treatments that removed alternate lateral buds on the entire floricanne or all the buds on the lower half of the cane or all of the upper lateral buds on the cane. They found no yield compensation with the removal of alternate lateral buds or with the removal of all of the lateral buds on the lower half of the cane. When all of the upper half buds were removed from the cane, the lower fruiting laterals increased in yield by 150-184%. The increase in the number of fruit was both an increase in the number of fruiting laterals and an increase in berries per lateral. This compensation could be from a source/sink relationship, or it could be because of increased light with a decreased number of laterals. Nevertheless, the treatments stimulated more flowers to set fruit.

Vasilakakis and Dana (1978) conducted some research on loss of flower buds on raspberry and any ability of the plant to compensate in yield. By removing 50% and 75% of the total number of whole inflorescences, they found a slight increase in individual fruit weights. However, they did not clip individual buds and, therefore, these treatments are not likely to produce the same response as SBW injury exposure. All of these studies suggest that raspberry does have compensation potential when certain resource sinks are removed. However, none of them have specifically evaluated the effect of sink loss and compensation at the individual flower bud level, similar to SBW injury.

Compensation by Crops for Bud Damage by *Anthonomus* spp.

Compensation for SBW flower bud damage or bud removal has not been studied specifically in raspberries. However, compensation by other crops when exposed to *Anthonomus* species has been studied. Pritts *et al.* (1999) examined twelve strawberry

cultivars for the ability of the plants to compensate in yield when exposed to SBW. By manually clipping flower buds of specific orders of berries, they found that most of the varieties examined could compensate for bud loss when the damage occurred early in inflorescence development prior to bloom. Yields were only reduced 12% when all primary flower buds were clipped and by 14% when all tertiary berries were removed. When primary buds were clipped, strawberry plants increased production of fruit from higher order buds (i.e. tertiary or quaternary). Cultivars also compensated by increasing average fruit weight. The ability of the plant to compensate was decreased over time beyond bloom. Compensation ability was dependant on cultivar, with some able to tolerate 35% bud loss, while others could not tolerate 12% without significant loss of yield.

Cranberry crops can be damaged by a weevil similar to SBW, the cranberry weevil (*Anthonomus musculus*), which inflicts the same type of damage on the cranberry plant. By simulating cranberry weevil injury on cranberry plants, Long and Averill (2003) found that when 67% of the buds were removed from 'Early Black,' there was a 37% decrease in yield, but when only 33% of the buds were removed, there was complete compensation for yield loss with increased fruit set. In another trial, they examined the effect of when the buds were clipped, early, late or not clipped, at four sites. When 50% of the buds were clipped off each flower cluster early or late in the season, there were no differences found in yield measured between the high amounts of damage early and late in the season. However, any clipping, early or late, resulted in 30% decrease in fruit number and weights compared with the control treatments. These studies show that the cranberry plant can compensate for some low levels of weevil damage. However, more

information is required to determine how this might effect control threshold recommendations (Long and Averill, 2003).

Stewart *et al.* (2001) looked at different levels of prebloom square (bud) loss in cotton by simulating boll weevil (*Anthonomus grandis*) damage. The cotton plant can compensate for the loss of small flower buds (buds clipped earlier in the season) more easily than large buds (buds clipped later in the season) because the plant has invested more energy and resources into the larger fruiting structure than the smaller structure and because the plant has less time to recover from the damage later in the season. Two mechanisms for compensation were suggested for yield after bud loss. Early bud clipping increased the survival rates of the unclipped buds and it increased the weight of the lint produced. Late season bud clipping decreased the weight of the lint produced. Overall, this study demonstrates that cotton plants can compensate for low levels of simulated weevil bud damage but that the timing of bud loss significantly effects how plants respond.

The timing that the damage occurs is key to the plants ability to compensate. The later the damage occurs in the growing season, the less time the plant has to compensate for the damage before the canes expire, therefore, the damage that occurs later may be more harmful to the overall yield. SBW inflicts damage to strawberry plants over a period of four weeks (Bostainian *et al.*, 1999) so some later cultivars may not be susceptible to SBW damage. This also relates to *Anthonomus* species damage on cotton (Stewart *et al.* 2001) but conflicts with Long and Averill (2003) findings of *Anthonomus* damage on cranberry crops.

Overall Research Objective

Research on plant compensation in response to *Anthonomus* species damage is altering how scientists are looking at SBW damage and how it may affect crop yields and, therefore, monetary profits from the crop. The strawberry, cranberry and cotton plants may be able to compensate for a loss of buds at certain points in development, which vary between crops and cultivars. There is a possibility that some compensation may occur in raspberry following bud loss due to SBW damage. There are no studies to date examining individual buds clipped from raspberry plants and how that may affect yields. However, it is known that the raspberry plant only uses a small percentage of the carbohydrate reserves in its roots for the current season's crop (Fernandez and Pritts, 1993), and that raspberry plants can compensate if some larger sinks are damaged early in the season (Moore, 1994). This suggests that raspberry plants may be able to compensate for some level of SBW damage. However, more study of the effects of individual flower bud loss needs to be carried out before conclusions about yield compensation from SBW damage can be drawn.

EFFECT OF FLOWER BUD REMOVAL ON FRUITING IN RED RASPBERRY: EVALUATING POTENTIAL IMPACT OF STRAWBERRY BUD WEEVIL

INTRODUCTION

Strawberry Bud Weevil (SBW), *Anthonomus signatus*, is a potentially important pest of raspberry in the Northeastern United States. The effect of SBW on strawberry is well documented (Bostanian *et al.*, 1999; Easterbrook *et al.*, 2003; Khanizadeh *et al.*, 1992; Kovach, 1995; Kovach *et al.*, 1999; Mailloux, 1993; and Pritts *et al.*, 1999), but the economic impact on raspberry is unknown. This insect is commonly known as “clipper,” because of the females’ behavior of laying their eggs in flower buds and then severing, or “clipping,” the bud from the plant (Pritts *et al.*, 1999).

Although raspberries have been cited as hosts for clipper, its potential economic impact on this crop has not been studied. Observations by several entomologists (J. Dill, A. Eaton, D. Handley and S. Schloemann, 2004) in the region have suggested that SBW may be responsible for raspberry flower bud losses approaching 75% in New England. Yet few growers recognize the problem because the damage occurs early in the season, prior to typical pesticide applications. If raspberries are a suitable host for SBW and flower bud losses resulting from its activity are high, this insect could be causing significant economic damage to commercial raspberry crops. Detailed information regarding the activity of SBW on raspberry and the plants’ ability to tolerate this injury could help farmers decide when, and if, management efforts for this insect are needed to prevent significant crop losses.

Manual clipping of strawberry flower buds early in their development causes compensation in yield whereby a large number of buds may be clipped with minimal loss of yield (Pritts *et al.*, 1999). Strawberries compensate for flower bud loss by producing

additional high order buds that result in a greater number of fruit per plant (Pritts *et al.*, 1999). This ability to compensate decreases when clipping occurs at a later stage of bud development. Raspberries can compensate in yield when lateral buds are removed in the dormant stage by producing additional lateral buds (Fernandez and Pritts, 1996; Moore, 1994; Waister and Barritt, 1980). Raspberry plants can also compensate for the removal of primocanes (Fernandez and Pritts, 1993; Gundersheim and Pritts, 1991; Oliveira *et al.*, 2004). However, later damage to the plants that would coincide with SBW damage has not been tested.

Second year raspberry canes (floricanes) have fruiting laterals at each node on the cane. Each lateral has the potential to produce a primary bud at the end of the lateral and two or three secondary buds just below the primary bud. These buds combined comprise the terminal cluster. Below the terminal cluster, smaller, secondary buds occur at each node on the lateral. In some instances, tertiary buds may occur on nodes below the secondary buds. This branching lateral flower structure is referred to as a racemose inflorescence (Logsdon, 1974). Primary, secondary and tertiary berry descriptions are referred to as 'berry orders' in this paper.

Fruit yield compensation in response to clipped buds has been found in strawberry plants, another host of SBW, and may provide a means for plants to tolerate clipping injury without impacting yield. Pritts *et al.*, (1999) examined twelve strawberry cultivars for the ability of the plants to compensate in yield when exposed to SBW. By manually clipping flower buds of specific orders of berries, they found that most of the cultivars could compensate for bud loss when the damage occurred early in inflorescence development. Primary fruit weights make up about 15%, secondary fruit weights make up

about 14%, and tertiaries make up about 14% of the total fruit yield, the rest of the yield being unmarketable, small or diseased, fruit, but these figures vary depending on the cultivar (Moore *et al.*, 1970; Sherman and Janick, 1966; Webb *et al.*, 1974). Pritts *et al.* (1999) found yields were reduced by 12% when all primary flower buds were clipped and by 14% when all tertiary buds were removed. When primary buds were clipped, strawberry plants seemed to produce additional higher order buds. Some cultivars compensated by increasing the number of fruit produced and some increased the average fruit weight of the fruit that was left. They also found that the ability of the plant to compensate was decreased as the buds developed over time. Pritts *et al.*, (1999) concluded that the strawberry plants' ability to compensate for clipped buds should reduce the perceived impact of SBW.

The raspberry plant's mechanisms for increasing fruit size are different than in strawberry, so the methods for the plants to compensate are also different. Strawberries are made up of multiple seeds (achenes) which are located on the surface of an edible receptacle (Abbott *et al.*, 1970). The size of the berry is dependant on how many achenes develop and how much the cells of the receptacle expand, which is dependant on many other factors including successful pollination and fertilization (Abbott *et al.*, 1970). Differently than strawberry, as a raspberry seed develops it will form a hard seed coat (the endocarp), then a cover of flesh (the mesocarp) and skin (the exocarp). This all together forms a peach-like structure called a drupe (Robbins *et al.*, 1988). About 100 drupes per berry all rest on a single inedible receptacle. As each drupe develops, the mesocarp cells elongate as the drupe increases in size (Reeve, 1953). Similar to strawberry (Janick and Eggert, 1968), raspberry flowers have a predetermined number of

seeds that is set at flower initiation in the fall or early spring, therefore, the number of drupes that make up one berry is already determined before the flower develops in the late spring (Dale and Daubeny, 1987). Abbott *et al.*, (1970) found that the strawberry receptacle expands to increase the fruit size of the berry during development in the spring. This is different from the cell expansion of the raspberry drupes because each drupe acts as an individual sink versus a strawberry receptacle, which is a single sink with many cells (Abbott *et al.*, 1970). The mechanisms for cell enlargement in these different flower parts in the raspberry and strawberry illustrate how different these crops are in terms of fruit growth and size.

Moore (1994) examined the ability of raspberry plants to compensate for loss of lateral buds. Of eleven different varieties studied, up to 50% of lateral buds could be removed from dormant canes without having significant impact on subsequent yield. The plants appeared able to compensate for loss of buds when laterals were removed from a cane by stimulating secondary buds to break and produce a replacement fruiting lateral shoot. However, SBW damage occurs significantly later in the developmental cycle than the reported lateral bud removal, and therefore may preclude any yield compensation ability. Vasilakakis and Dana (1978) conducted some research on loss of flower buds on raspberry and the ability of the plant to compensate in yield. By removing 50% and 75% of the total number of whole inflorescences, they found a slight increase in individual fruit weights. However, they did not clip individual buds and, therefore, did not examine the potential damage from SBW exposure.

RESEARCH OBJECTIVE

The objective of this study was to evaluate the yield compensation potential of two raspberry varieties subjected to various levels of flower bud removal that simulate damage by strawberry bud weevil.

EXPERIMENT I – MATERIALS AND METHODS

On 1 March 2005, 30 dormant raspberry plants (cv. ‘Killarney’) were planted into 13.2 liter pots with Fafard Mix No. 2 (Conrad Fafard, Inc., Agawam, MA) in an unheated hoophouse. ‘Killarney’ is an early maturing, small fruited raspberry with an average fruit weight of three grams (Schloemann *et al.*, 2000). Each pot received 50g of Osmocote (14-14-14) (The Scotts Company LLC, Marysville, OH) at planting and 150 ppm of N every other week. The plants were watered every day as needed. The pots were aligned in single pot plots as a randomized complete block with six replications and five treatments. When the flower buds emerged and the terminal buds on the laterals had reached approximately 0.5 cm in diameter, one lateral per pot was tagged and treated with one of the following treatments (Figure 1.1):

1. Control (no clipping)
2. Clip all primary buds
3. Clip all secondary buds
4. Clip all primary and secondary buds
5. Clip all tertiary buds

The data collected included number of berries harvested from each lateral, the ‘order’ of the berry on the inflorescence (primary, secondary, or tertiary), weight of the individual berry and the number of drupes that make up each berry. The data was analyzed by general linear model analysis of variance with mean separation by least significant difference. Yield compensation is defined as the plants ability to make up for

reduction in yield components, such as the number of fruit and the size or weight of the fruit harvested (Crandall, 1995; Dale 1989; and Waister and Barritt, 1980).

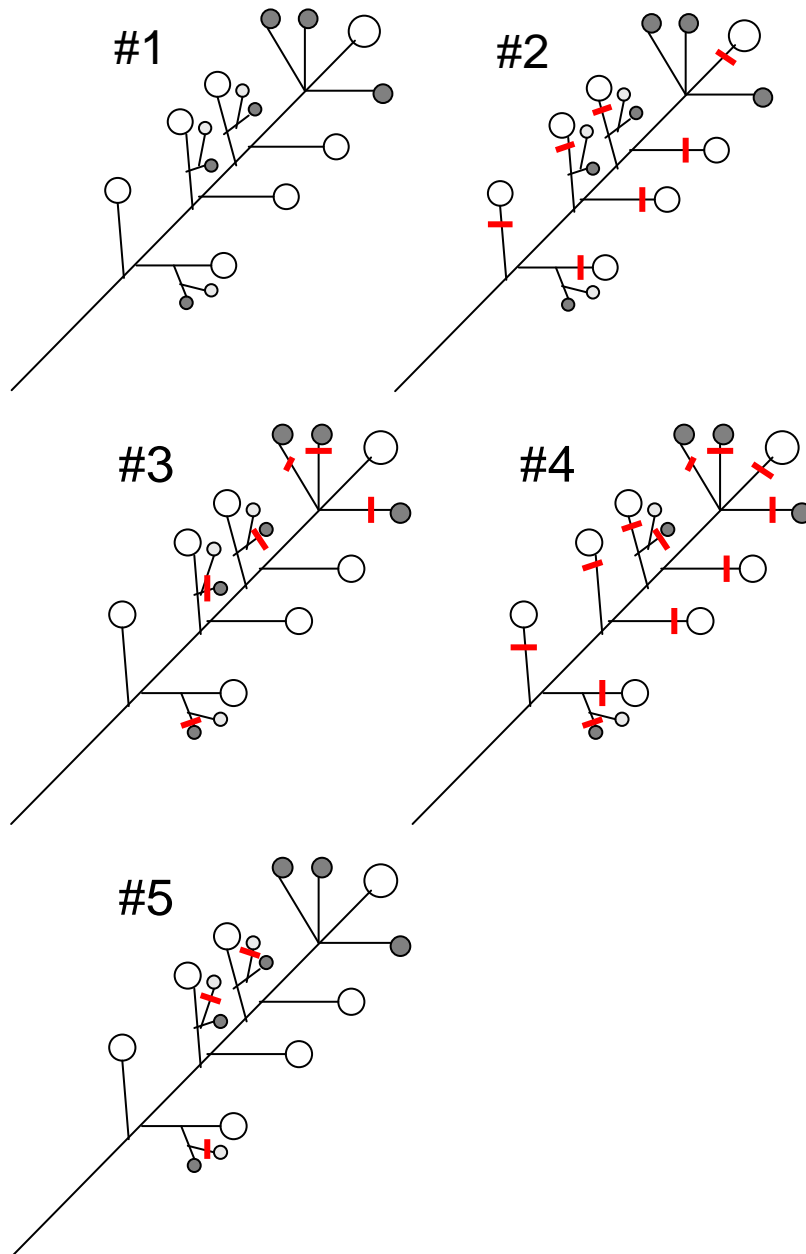


Figure 1.1. Diagram of a raspberry lateral in 2005. The white, dark gray and light gray circles correspond to the primary, secondary and tertiary buds respectively. The numbers to the left of each lateral correspond to treatment number as follows: #1: Control- no clipped buds, #2: Clip the primary flower buds on each lateral, #3: Clip all secondary flower buds, #4: Clip all primary and secondary buds, #5: Clip all tertiary buds. The actual number of secondary and tertiary buds vary on each lateral for each plant. Cross marks correspond to buds clipped off.

EXPERIMENT I – RESULTS AND DISCUSSION

Total yield per lateral was reduced by all of the clipping treatments. When primary buds alone were clipped, secondary berry weight and tertiary berry weight did not change. When secondary buds were clipped, primary and tertiary berry weights were unchanged. When both primary and secondary buds were clipped, tertiary berry weight increased by 282%. When tertiary buds were clipped, primary berry weight was unchanged while secondary berry weight decreased (Table 1.1). Average berry size in weight was not affected by any of the clipping treatments (Table 1.2).

Table 1.1. Total weight (g) per lateral of each treatment and each berry order for ‘Killarney’ raspberry in 2005.

Treatment	Total	Primary	Secondary	Tertiary
No Clipping	52.8a	19.9a	28.5a	4.37bc
Clip Primary Buds	23.2b	--	17.9ab	5.30b
Clip Secondaries	18.6b	14.8a	--	3.80bc
Clip Primaries and Secondaries	12.3b	--	--	12.3a
Clip all Tertiaries	29.6b	15.1a	14.5b	--
	*** ^z	***	***	***

^z ‘***’ refers to a p-value of .001

Table 1.2. Average berry weight (g) of each berry order for ‘Killarney’ raspberry in 2005.

Treatment	Primary	Secondary	Tertiary
No Clipping	4.12	3.55	1.49
Clip Primary Buds	--	2.98	1.70
Clip Secondaries	3.81	--	1.56
Clip Primaries and Secondaries	--	--	1.86
Clip all Tertiaries	3.84	3.04	--
	NS ^z	NS	NS

^zNS corresponds to no significant difference.

When primary buds were clipped, the number of secondary berries and the number of tertiary berries did not change. When secondary buds were clipped, the number of primary and tertiary berries was unchanged. When primary and secondary buds were clipped, the number of tertiary berries increased by 307%. When the tertiary buds were clipped, the number of primary berries was unchanged and the number of secondary berries decreased (Table 1.3).

Table 1.3. Total number of berries per lateral of each berry order for ‘Killarney’ Raspberry in 2005.

Treatment	Total	Primary	Secondary	Tertiary
No Clipping	15.17a	4.83a	8.17a	2.17bc
Clip Primary Buds	9.33ab	--	5.83ab	3.17b
Clip Secondaries	5.83b	3.83a	--	2.00bc
Clip Primaries and Secondaries	6.67b	--	--	6.67a
Clip all Tertiaries	7.83b	4.00a	3.83b	--
	** ^z	***	***	***

^z ‘**’ and ‘***’ correspond to p-values .01 and .001 respectively.

The ability of raspberry plants to compensate for flower bud loss in terms of subsequent yield was very limited. There was slight to no compensation in total fruit weight, average berry weight, and number of berries when just the primary buds are clipped or just the secondary buds are clipped. When only tertiary buds are clipped, the primary berries stay the same in count and total weight and secondary berries decrease in number and total weight. This suggests that none of these treatments created enough of a sink loss to stimulate a compensatory response, or that the plants simply have no mechanism to compensate for this sort of injury. This may be because the injury occurs too late in the developmental stage of the buds and plant (Dale and Daubeny, 1987).

When both the primary and secondary buds are clipped (i.e. a lot more damage than any other treatment), the tertiary berry total weight and berry numbers increase by ~300%. Despite the jump in weight and berry numbers, the tertiary berries do not fully compensate for the yield loss. Tertiary berries alone yielded only about one quarter as much as an undamaged plant with primary and secondary fruit. This being said, an increase of 300% is a large amount of compensation. The reason the plant was stimulated to compensate in this treatment could be that the amount of damage inflicted on the plant was enough to initiate the compensatory response from the plant, whereas the other treatments did not inflict enough damage. Another reason the plant could have had this very large compensatory response is that the damage took place at a time in the plants development that stimulated those buds that were not far along in their development to mature, when, under no simulated SBW damage, the plant would not have needed those buds to mature, therefore aborting them. This concept was demonstrated by Crandall *et al.* (1980) and Moore (1994) by removing different parts of the plant and getting similar compensatory yield results.

EXPERIMENT II – MATERIALS AND METHODS

The set up and treatments of Experiment II in 2006 were altered from the 2005 Experiment I set up and treatments due to the results of the research done in Experiment I. In 2006, two cultivars are used instead of one, the designation of which buds are primaries, secondaries and tertiaries are different (Figure 1.2), bumble bees were brought in to pollinate the flowers, and the treatments were altered to correspond to the different designations of bud orders. These changes were made, after trying the experiment on a smaller scale for one year, to increase the amount of information gathered from the study the second year. In 2005, the bud order designations included multiple primaries developing on every lateral. In 2006 the primary bud is designated only at the terminal end of the lateral. In 2005, it was observed that the buds that develop all the way down the lateral develop after the primary bud, therefore, should be designated secondaries, not primaries.

Raspberry plants (cv. Killarney and Encore) were started in the spring of 2005 in 13.2 liter pots with Fafard Mix No. 2 (Conrad Fafard, Inc., Agawam, MA) and grown in a greenhouse until 2 August 2005. The pots were then moved outdoors where they were placed on landscape fabric. The canes were attached to a temporary trellis and continued to be fertilized weekly through September with Peters Professional 20-20-20 (The Scotts Company LLC, Marysville, OH) at a rate of 150 ppm. The pots were moved into an unheated storage for the winter months and covered in coarse sawdust. The plants were removed from storage 1 March 2006 and placed in an unheated high tunnel on landscape fabric. Each potted plant was pruned to two floricanes.

Thirty pots each of the two cultivars were arranged in a RCB design with single pot plots, five treatments and six replications. When a treatment was applied, every lateral on the plant was treated. The plants were treated as each bud reached .5 cm in diameter. Clipping took place over the course of four weeks, the time a SBW would be in the field (Bostonian et al., 1999). When the flower buds emerged and the terminal buds on the laterals had reached approximately 0.5 cm in diameter, the following treatments were applied to each variety (Figure 1.2):

1. No clipped buds
2. Clip the primary (largest) flower bud on each lateral
3. Clip only two (or three) secondary flower buds in the terminal cluster (leave primary and the rest) on each lateral
4. Clip all flower buds except the primary on each lateral
5. Clip all flower buds except primary and two secondary buds in the terminal cluster on each lateral

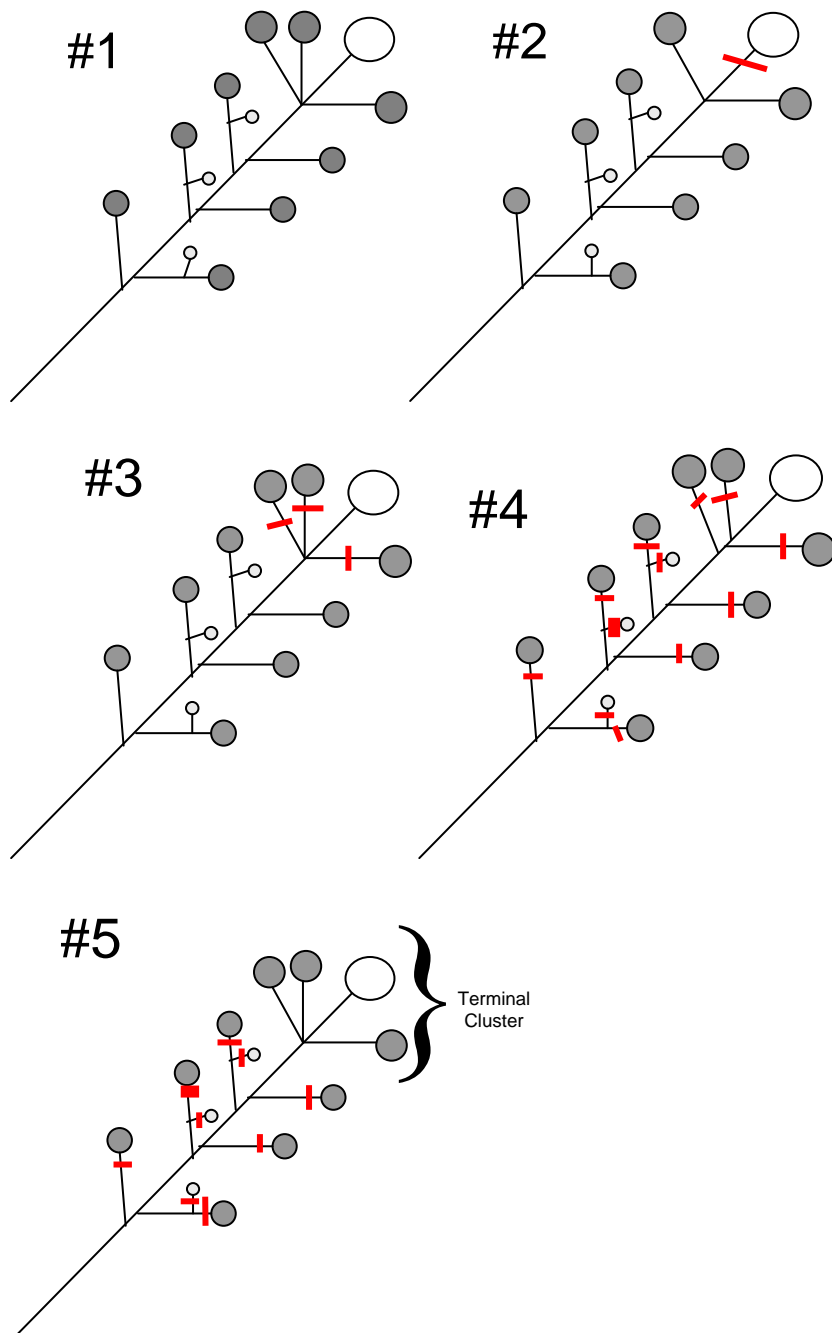


Figure 1.2. Diagram of a raspberry lateral. The white, dark gray and light gray circles correspond to the primary, secondary and tertiary buds respectively. The numbers to the left of each lateral correspond to treatment number as follows: #1: Control- no clipped buds, #2: Clip the primary (largest) flower bud on each lateral, #3: Clip only two (or three) secondary flower buds in the terminal cluster (leave primary and the rest) on each lateral, #4: Clip all flower buds except the primary on each lateral, #5: Clip all flower buds except primary and two secondary buds in the terminal cluster on each lateral. The actual number of secondary and tertiary buds vary on each lateral for each plant. Cross marks correspond to buds clipped off.

Three laterals were randomly selected from the top third of each plant and tagged. An active bumble bee hive (Koppert Biological Systems, the Netherlands) was placed in the hoophouse for pollination of the raspberry flowers. All of the fruit from the tagged laterals were harvested for data. The data recorded for each berry harvested included the ‘order’ on the inflorescence (primary, secondary, or tertiary) and the weight of the individual berries. The data was analyzed by general linear model analysis of variance with mean separation by least significant difference and by single degree of freedom t-tests.

EXPERIMENT II – RESULTS AND DISCUSSION

Total Fruit Yield

Removal of the primary bud or two secondary buds from the terminal cluster on a fruiting lateral did not affect total fruit yield of the Killarney cultivar. Clipping all buds except the terminal cluster, or clipping all but the primary bud reduced the total yield of the raspberry canes by up to 93%. Results were similar for ‘Encore’ (Table 1.4).

Table 1.4. Total fruit weight (g) per three laterals of the Killarney and Encore cultivars

Treatment	Killarney	Encore
Control	133.7a	184.6a
Clip Primary Buds	148.8a	194.3a
Clip 2 Secondary Buds	142.1a	180.2a
Clip all but Terminal Cluster	31.4b	44.3b
Clip all but Primary Bud	8.12b	20.95b
	*** ^z	***

^z ‘***’ corresponds to a p-value of .001

None of the treatments affected the total weight of the primary berries. Clipping two secondary buds on each lateral, or clipping only the primary bud did not change the total yield of secondary berries in both cultivars. Clipping all buds except the primary, or all but the terminal cluster decreased secondary fruit total yield by up to 77% in ‘Killarney’ and 78% in ‘Encore’. This treatment caused too much damage for the plant to compensate for the lost yield with berry size. Tertiary berry total fruit yield was not affected by any of the treatments except when all the tertiary berries were clipped (treatments 4 and 5) (Figure 1.3, Table 1.5, Table 1.6).

Table 1.5: Total fruit yield (g) per three laterals for each berry order for ‘Killarney’ raspberry.^z

Treatment	Total	Primary	Secondary	Tertiary
No Clipping	134a	9.39	102a	22.5
Clip Primary Buds	149a	--	114a	35.0
Clip 2 Secondary Buds	142a	7.97	94.3a	39.8
Leave Terminal Cluster	31.4b	8.27	23.2b	--
Clip all but Primary Bud	8.12b	8.12	--	--
	***	NS	***	NS

^z ‘***’ corresponds to a p-value of .001, ‘NS’ means no significance

Table 1.6: Total fruit yield (g) per three laterals for each berry order for ‘Encore’ raspberry.

Treatment	Total	Primary	Secondary	Tertiary
No Clipping	185a	13.8b	153a	18.0
Clip Primary Buds	194a	--	175a	19.0
Clip 2 Secondary Buds	180a	12.5b	132a	35.6
Leave Terminal Cluster	44.2b	11.2b	33.0b	--
Clip all but Primary Bud	20.9b	20.9a	--	--
	*** ^z	***	***	NS

^z ‘***’ corresponds to a p-value of .001

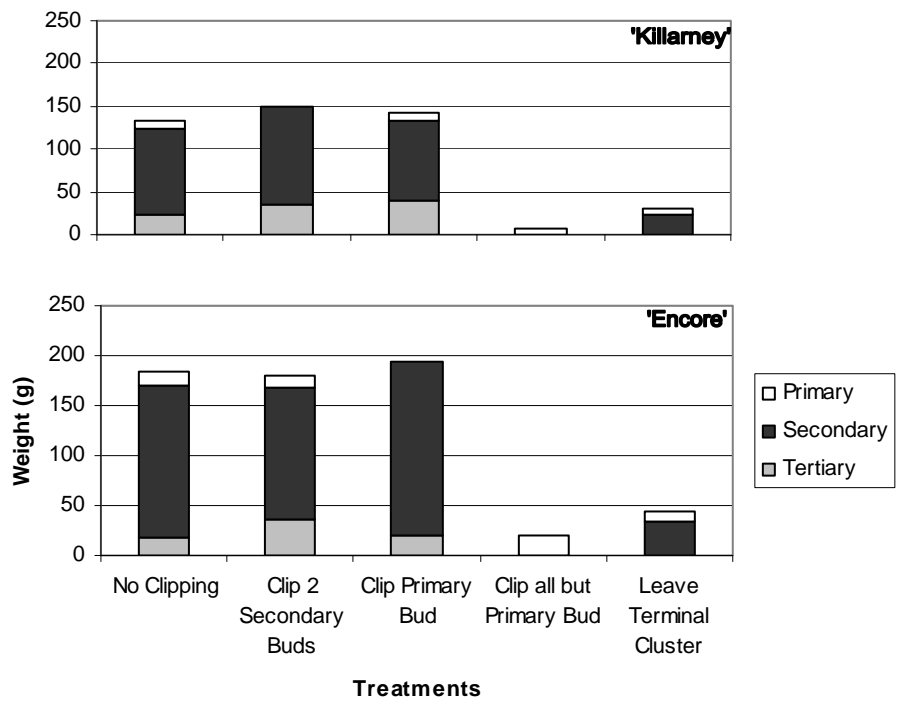


Figure 1.3. Total fruit yield from a subset of three laterals of 'Killarney' and 'Encore'.

The p-values are 0.7192, 0.0001, and 0.0001 for the 'Killarney' primary, secondary and tertiary data respectively. The p-values are 0.0001, 0.0001, and 0.0097 for the 'Encore' primary, secondary and tertiary data respectively.

Average Berry Weight by Berry Order

For both cultivars, clipping only the primary bud or all but the terminal cluster, increased the secondary berry size, but not the tertiary berry size. When all but the terminal cluster was clipped, the primary berry did not increase or decrease in average fruit size because it is likely that the primary berry already obtained its full potential resources by the time clipping occurred at the secondary and/or tertiary level (Crandall, 1995; Logsdon, 1974). When all but the terminal cluster was clipped, the secondary berry size increased. Other treatments did not affect berry size (Figure 1.4, Table 1.7, Table 1.8).

Table 1.7: ‘Killarney’ average berry size (g) by berry order^z

Treatment	Primary	Secondary	Tertiary
Control	2.51	2.99c	2.44
Clip Primary Buds	--	3.36ab	2.68
Clip 2 Secondary Buds	2.79	3.21bc	2.42
Clip all but Terminal Cluster	2.43	3.66a	--
Clip all but Primary Bud	2.55	--	--
	NS	***	NS

^z ‘***’ corresponds to a p-value of .001, ‘NS’ means no significance

Table 1.8: ‘Encore’ average berry size (g) by berry order^z

Treatment	Primary	Secondary	Tertiary
Control	4.96b	4.67b	3.48
Clip Primary Buds	--	5.09ab	3.55
Clip 2 Secondary Buds	5.45ab	4.80b	3.63
Clip all but Terminal Cluster	4.93b	5.49a	--
Clip all but Primary Bud	5.97a	--	--
	***	***	NS

^z ‘***’ corresponds to a p-value of .001, ‘NS’ means no significance

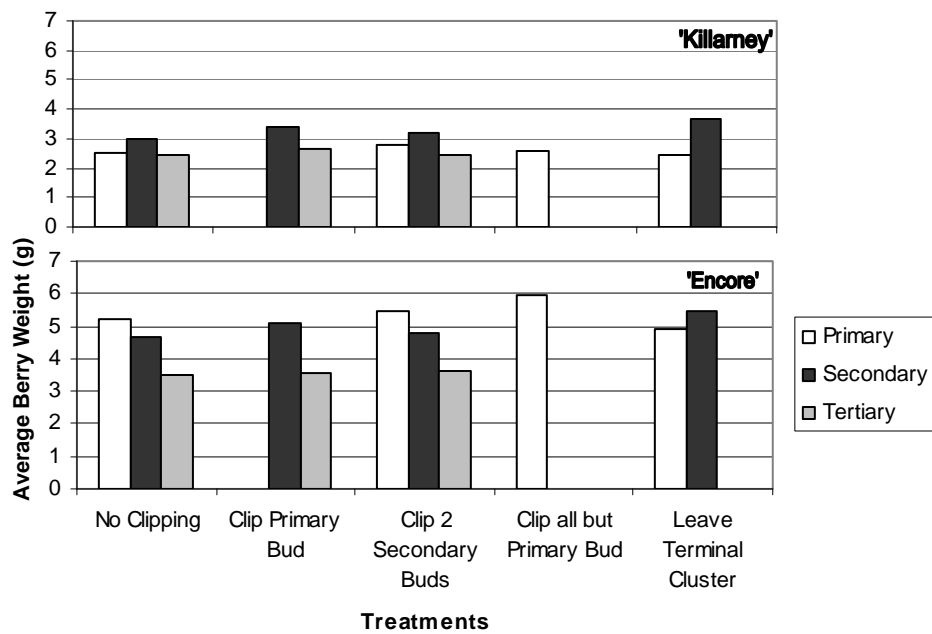


Figure 1.4. Average berry weight (g) for each treatment of ‘Killarney’ and ‘Encore’.

The p-values are 0.1279, 0.0001, and 0.0001 for the ‘Killarney’ primary, secondary and tertiary data respectively. The p-values are 0.0001, 0.0001, and 0.0001 for the ‘Encore’ primary, secondary and tertiary data respectively.

Total Number of Berries Harvested

Clipping the top two ('Killarney') or three ('Encore') secondary buds in the terminal cluster resulted in a decrease in the number of primary berries produced in 'Killarney' and had no effect on primary berries in 'Encore'. This treatment had no effect on the total number of secondary berries produced. Since secondary buds were being clipped off and no decrease in the secondaries was observed at harvest, this suggests some compensation was occurring at the secondary bud level. This same treatment stimulated an increase in the number of tertiary berries produced in both cultivars. So, in addition to not reducing the secondary berry total, the number of tertiaries were increased. This might occur because the buds were clipped early in development, allowing plants time and resources to support more tertiary bud development instead of typical bud abortion (Figure 1.5, Table 1.9, Table 1.10).

Table 1.9: 'Killarney' total number of berries harvested per three laterals^z

Treatment	Total	Primary	Secondary	Tertiary
Control	47.0a	3.83a	33.7a	9.50b
Clip Primary Buds	46.3a	--	33.8a	12.5ab
Clip 2 Secondary Buds	48.6a	2.83b	29.3a	16.5a
Clip all But Terminal Cluster	9.66b	3.33ab	6.33b	--
Clip All But Primary Bud	3.17b	3.17ab	--	--
	***	***	***	***

^z '***' corresponds to a p-value of .001

Table 1.10: 'Encore' total number of berries harvested per three laterals^z

Treatment	Total	Primary	Secondary	Tertiary
Control	40.2a	2.50	33.0a	4.67
Clip Primary Buds	40.0a	--	34.5a	5.50
Clip 2 Secondary Buds	39.9a	2.33	26.8a	10.8
Clip all but Terminal Cluster	8.33b	2.33	6.00b	--
Clip All But Primary Bud	3.50b	3.50	--	--
	***	NS	***	NS

^z '***', '***' corresponds to a p-value of .01, .001 respectively, 'NS' means no significance

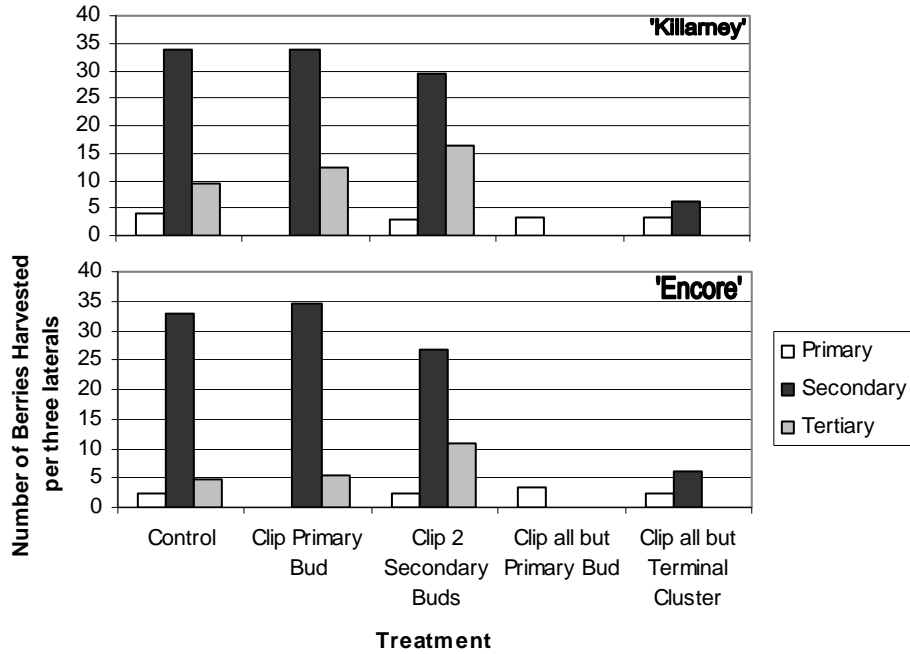


Figure 1.5. Average number of berries harvested from a subset of 3 laterals per plant for each treatment for ‘Killarney’ and ‘Encore’.

The p-values are 0.0042, 0.0001, and 0.0001 for the ‘Killarney’ primary, secondary and tertiary data respectively. The p-values are 0.0003, 0.0001, and 0.0188 for the ‘Encore’ primary, secondary and tertiary data respectively.

Clipping all buds, except those in the terminal cluster, had no significant effect on the number of primary berries produced. This treatment decreased the number of secondary berries for both cultivars because most of the secondary buds were clipped off, leaving only two berries in the terminal cluster. Clipping all but the primary berry reduced the total number of berries by about 92% for both treatments. Clipping just the primary bud did not affect the total number of berries produced by the plant. It is important to note that the primary berry is typically only a small amount larger than each secondary berry; therefore, a loss of multiple secondary berries can greatly impact yields.

CONCLUSIONS

In our study, various levels of flower bud removal from raspberry fruiting laterals to mimic SBW injury demonstrated that the impact on yield will depend upon the number of buds lost, their position on the inflorescence and the cultivar of raspberry affected. Field surveys of SBW injury on raspberries (Howard, unpublished data) have shown that bud loss can exceed 55% of the buds present on a cane. Yet, growers rarely acknowledge this insect as a significant pest. If the raspberry plant can compensate for bud loss, either through increased fruit size on remaining buds or the set of additional fruit following the injury, perhaps any such loss would not have significant economic impact. Such an effect has been observed in certain strawberry varieties (Pritts *et al.*, 1999).

Clipping the primary flower bud and leaving the rest of the crop on each lateral on the cane had no effect on total yield in either variety. Removal of the primary bud increased secondary fruit size for both varieties, suggesting that removal of the primary as a sink may allow more resources to go to secondary fruit and stimulate increased fruit size, resulting in approximately the same total yield as it would with a full crop. This

treatment did not change the total number of berries produced by the raspberry canes. Therefore, it is unlikely that increasing fruit number is a mechanism for compensation, despite increased resources available. This may be because fruit number is determined prior to the injury and further flower bud development is not possible unless through reductions in the relatively “normal” rate of higher bud abortion.

Clipping only two (or three) secondary berries from every lateral on a cane did not have a significant impact on total yield. Clearly, the compensatory response was enough to fully compensate for the loss of those berries. Thus, it seems unlikely that clipper injury at this level would pose an economic threat.

Clipping all of the buds except the terminal cluster reduced total yields by 76% in the Killarney and the Encore cultivars. While there was an increase in the secondary berry size, the level of compensation was not enough to produce yields equal to the control. In both varieties, this treatment increased the number of tertiary berries produced. This result demonstrates apparent compensation by the plant by setting smaller, later-ripening berries to make up for the loss of the larger, earlier berries. It is important to note that the secondaries comprise the largest number and weight of fruit making up the total yield. Therefore, removing most of those buds also subtracted most of the yield from the total, resulting in the largest sink removal of all the treatments, other than removal of all but the primary bud. However, this treatment also offered the greatest opportunity for compensation in the form of increased number of tertiaries developed, which were the least developed of any buds. With this treatment, there appears to have been a response both in terms of secondary fruit size and tertiary fruit number.

Similar to the treatment of clipping all but the terminal cluster, the treatment of clipping all of the buds except the primary bud on each lateral of the cane decreased the total yields by 93% in the 'Killarney' and 85% in the 'Encore'. There was some primary berry size compensation detected in the 'Encore' but not enough to produce yields equal to the control. Again, this treatment severely decreased a resource sink by clipping of all of the secondary buds, which could have induced tertiaries to develop that would not have developed with no clipping. In this case, the yield decrease was even greater than the treatment that clipped all but the terminal cluster, showing that this damage was even more severe and may have created a greater demand for the plant to compensate. Instead, the yield decreased even more. This may be because the damage occurred too late in the development of the plant, or that the damage was too severe for the plant to recover from, or both.

Experiment II illustrates two potential extremes of SBW injury to raspberry. Relatively minor bud loss of either a single primary bud or two secondary buds per lateral did not have a significant impact on yield. However, in the case of the primary buds, this was not due to any compensatory ability, but rather the relative insignificance of these few fruit in relation to the total yield. Relatively high levels of bud loss, including all but the primary buds in a cluster or all but the primary cluster on a fruiting lateral, decreased yields from 76% to 93%. In these cases, it is apparent that some compensation mechanisms can be stimulated, including increased fruit size and fruit number, through the loss of buds as sinks. However, these mechanisms are not adequate to replace the potential loss of yield. It is likely that the injury occurs too late in the development cycle, i.e. post flower initiation, to be able to adequately improve fruit number. Fruit size

compensation is probably limited by the structure of the fruit, which is dependant on number and size of individual drupes, as opposed to strawberry, whose size is governed by a large fleshy receptacle. While some compensation effects on fruit size were apparent, these were not nearly adequate to bring yields up to the control yields, and these effects clearly differed between varieties. It is not clear from this study if the compensation effects observed in berry size were a result of increased numbers of drupes per fruit and/or an increase in individual drupe size on each berry. However, in strawberry the number of seeds is predetermined before SBW damage occurs and should compensation ensue, it is observed in cell enlargement to increase the fruit size. It is also known in raspberries that the flower initiation takes place in the fall before overwintering (Crandall, 1995; Dale and Daubeny, 1987), so this would be cause to assume the compensation that happens in the spring would be cell enlargement, not increased number of seeds developing. Further research should include bud clipping levels somewhere between the two extremes used in this study.

EVALUATING RED RASPBERRY RESPONSE TO FLOWER BUD LOSS ON A FIELD GROWN CULTIVAR, ‘REVEILLE’ RED RASPBERRY: ASSESSING POTENTIAL EFFECTS OF STRAWBERRY BUD WEEVIL

INTRODUCTION

Strawberry Bud Weevil (SBW), *Anthonomus signatus*, is a potentially important pest of raspberry in the Northeastern United States. The effect of SBW on strawberry is well documented (Bostanian *et al.*, 1999; Easterbrook *et al.*, 2003; Khanizadeh *et al.*, 1992; Kovach, 1995; Kovach *et al.*, 1999; Mailloux, 1993; and Pritts *et al.*, 1999), but the economic impact on raspberry is unknown. This insect is commonly known as “clipper,” because of the females’ behavior of laying their eggs in flower buds and then severing, or “clipping,” the bud from the plant (Pritts *et al.*, 1999).

Although raspberries have been cited as hosts for clipper, its potential economic impact on this crop has not been studied. Observations by several entomologists (J. Dill, A. Eaton, D. Handley and S. Schloemann) in the region have suggested that SBW may be responsible for raspberry flower bud losses approaching 75% in New England. Yet few growers recognize the problem because the damage occurs early in the season, prior to typical pesticide applications. If raspberries are a suitable host for SBW and flower bud losses resulting from its activity are high, this insect could be causing significant economic damage to commercial raspberry crops. Detailed information regarding the activity of SBW on raspberry and the plants’ ability to tolerate this injury could help farmers decide when and if management efforts for this insect are needed to prevent significant crop losses.

Manual clipping of strawberry flower buds early in their development causes compensation in yield whereby a large number of buds may be clipped with minimal loss

of yield (Pritts *et al.*, 1999). Strawberries compensate for flower bud loss by producing additional higher order buds that result in a greater number of fruit per plant (Pritts *et al.*, 1999). This ability to compensate decreases when clipping occurs at a later stage of bud development. Raspberry yield can compensate when lateral buds are removed in the dormant stage (Fernandez and Pritts, 1996; Moore, 1994) by producing additional lateral buds. Raspberry plants can also compensate for the removal of primocanes (Fernandez and Pritts, 1993, Gundersheim and Pritts, 1991; and Oliveira *et al.*, 2004). However, later damage that would coincide with SBW damage has not been tested.

RESEARCH OBJECTIVE

The objective of this study was to evaluate the effect of various levels of flower bud removal on subsequent yield and fruit characteristics of ‘Reveille’ raspberry, as might be experienced under field conditions when exposed to strawberry bud weevil.

MATERIALS AND METHODS

In the spring of 2006, a twelve meter row of established raspberry, cultivar Reveille at Highmoor Farm, Monmouth, ME was divided into four replicated blocks of three meter sections in a randomized complete block design. The following five treatments were applied to five canes in each block (twenty canes treated per treatment):

1. No clipped buds
2. 25 buds clipped per cane
3. 50 buds clipped per cane
4. 75 buds clipped per cane
5. 100 buds clipped per cane

On 31 May 2006, the treatments were applied when the terminal buds had reached an average of approximately 0.5 centimeter in diameter. The buds were clipped with a pair of sharp scissors with 17 millimeter blades. Flower buds were randomly clipped off

each cane according to the treatment applied; bud order was not taken into consideration. Each cane was tagged according to treatment. On 5 June 2006, the total number of buds on a sample cane from each of the four replications was counted to determine the average percent of buds clipped off the canes for each treatment. This average number of buds per cane, 335, was used to determine the percentage of buds clipped off for each of the treatments (Table 2.1). Berries were harvested when they had started to shed their receptacle. Harvest started on 5 July 2006 and continued until 25 July 2006. The fruit from each cane were counted and weighed. The data was analyzed by a general linear model analysis of variance with mean separation by least significant difference. Yield compensation is defined as the plants ability to make up for reduction in yield components, such as the number of fruit and the size or weight of the fruit harvested (Crandall, 1995; Dale 1989; and Waister and Barritt, 1980).

Table 2.1. The average percentage of buds clipped off raspberry canes for each treatment.

Treatment	% of Clipped Buds
Control	0a
Clip 25 buds per cane	7.9b
Clip 50 buds per cane	15.8c
Clip 75 buds per cane	23.7d
Clip 100 buds per cane	31.6e
	*** ^z

^z ‘***’ corresponds to a p-value of .001

RESULTS AND DISCUSSION

Each treatment yielded as many berries as the control canes (Figure 2.1). Yields per cane ranged from 53 berries for treatment 3 where 50 flowers were removed to 70 berries on canes where 100 buds were clipped. This indicates that even though a number of buds were clipped off, up to 100 per cane, the plant compensated for the clipping with approximately one new bud for each bud clipped.

The plants seemed to compensate fully for the number of buds clipped early in the bud development. The treatment that clipped 50 buds per cane (treatment 3) produced the least amount of berries, but this was not enough to significantly differ from the control canes. One reason that this treatment may have not compensated as much as the other canes is when the buds were clipped, all on the same day, some buds were full size, .5cm in diameter, and some were smaller. There may have been up to 50 buds at the 0.5cm stage, which were the targeted buds because they were ready to be clipped by the SBW. If 50 buds at the 0.5cm size were clipped, it seems that this would reduce yields because these buds have already been allocated a lot of resources by the plant, and this data shows that the yields were reduced. The treatments that clipped 75 and 100 buds (treatments 4 and 5, respectively) probably had about 50 buds at the 0.5cm stage and then more, smaller buds. Those 50 buds at the 0.5cm stage or bigger were clipped first. Then that left the smaller buds to be clipped to reach the total clipped buds for the treatment. This extra clipping of the smaller buds probably stimulated an extra response from the plant to compensate quickly for lost yield because the plant received a greater damage stimulus for compensation. The plants seemed to respond by producing increased numbers of berries to compensate for the clipped buds.

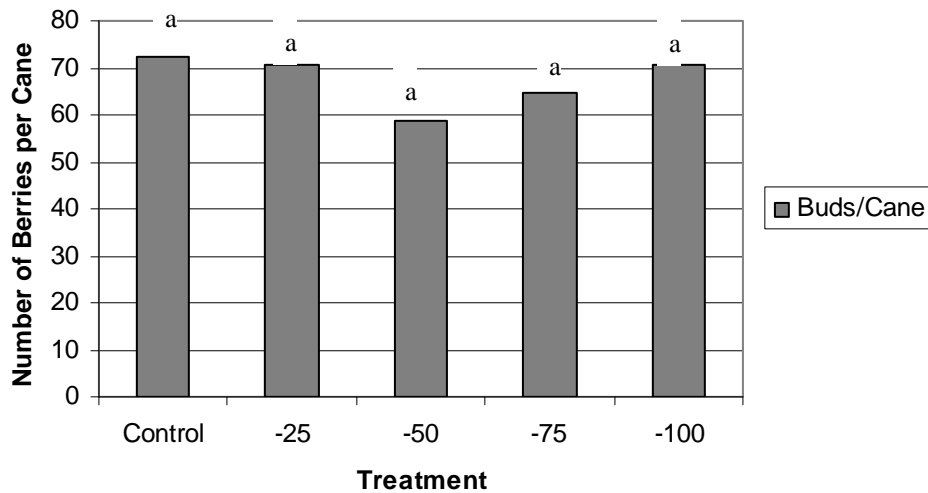


Figure 2.1. The average number of berries harvested per cane (P=0.9298).

Treatments are as follows: Control=no buds clipped per cane, and -25, -50, -75, and -100 are 25, 50, 75, and 100 buds clipped respectively per cane.

There were no significant differences between the treatments and the control plots when measuring total yield of the raspberry canes (Figure 2.2). The control treatment, 25 clipped buds per cane treatment (treatment 2) and treatment 5 yielded the most with around 160-166 grams per cane and treatment 3 yielded the least with 141 grams per cane. In this case, the highest damage level, clipping 100 buds per cane, seemed to produced yields comparable to the control, which may be because those canes had more, smaller buds clipped, therefore stimulating those canes to produce additional berries.

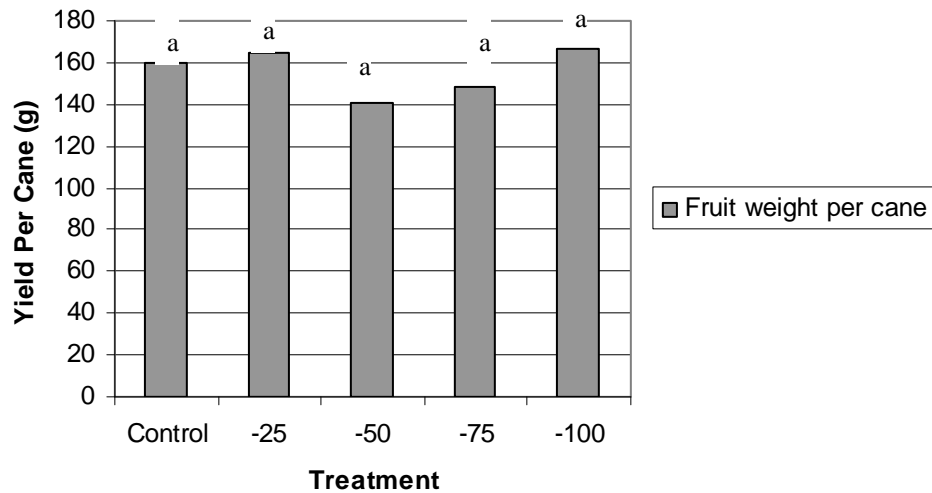


Figure 2.2. The total weight harvested per cane ($P=0.9678$).

Treatments are as follows: Control=no buds clipped per cane, and -25, -50, -75, and -100 are 25, 50, 75, and 100 buds clipped respectively per cane.

The bud clipping treatments did not significantly affect average berry weight (Figure 2.3). The average berry weight ranged from the control berries at 2.2 grams per berry to treatment 3 with 2.4 grams per berry. Treatment 3 probably had the largest berries because the larger buds got clipped off to begin with, but the damage was not heavy enough to stimulate extra bud production, so each bud that was left on the cane became a larger sink that could potentially allow increased fruit size. Since the plant produced fewer fruit, it had extra resources to distribute to the buds that were not clipped off.

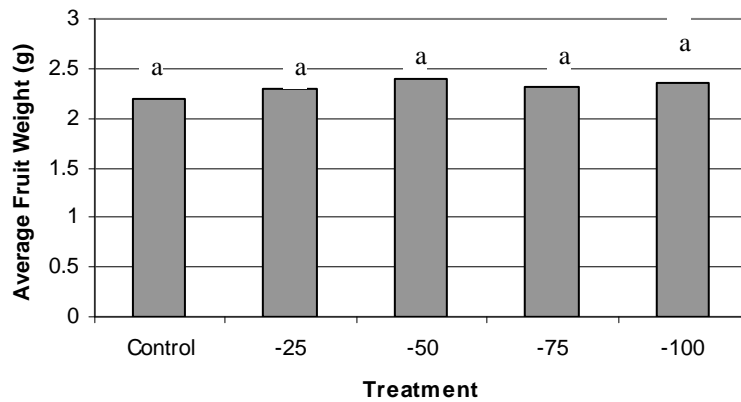


Figure 2.3. The average individual berry weight harvested per cane (P=0.7246).

Treatments are as follows: Control=no buds clipped per cane, and -25, -50, -75, and -100 are 25, 50, 75, and 100 buds clipped respectively per cane.

The total harvest weights (Figure 2.4) and the total number of berries harvested (Figure 2.5) for each treatment were not significantly different from the control treatment on any of the harvest dates. On the first harvest (5 July) the control treatment had the highest total yield with 271g. The other treatments were all around 100 grams. The control had higher yields than any of the other treatments to start because the remaining buds matured later in the clipping treatments. The control treatment also had the most number of berries harvested at 134 at the first harvest. The other treatments all had around 50 berries.

On the second harvest (10 July) the treatments all yielded around 500 grams. The control treatment had the most berries harvested with 274. Treatment 2 was close with 239 and the other treatments all yielded around 200 berries.

The third harvest (14 July), peak harvest, treatment 2 yielded the most at 511 berries and 1270 grams and treatments 4 and 5 yielded around 475 berries and 1200 grams. Treatments 3 and the control yielded the least amounts, each had around 425

berries and 1070 grams. Treatment 2 probably yielded the most at this point in the season because the largest control berries had already matured and it was the treatment with the least amount of damage aside from the control.

Yields at the fourth harvest (19 July) ranged from treatment 5 at 405 berries and 881 grams to treatment 3 at 294 berries and 653 grams. Treatment 5 started having yields comparable to the control treatment on this harvest date probably because this treatment endured the most damage, thereby stimulating the plants to produce more berries. The less severe treatments may not have incurred enough damage to threaten the raspberry plants' ability to produce fruit; therefore, the other treatments did not stimulate compensation for the damage as much as treatment 5.

The fifth harvest (21 July) ranged from treatments 2, 3, 5 and the control with around 160 berries and around 350 grams to treatment 4 at 114 berries and 235 grams. Treatment 4 probably yielded the least at this harvest because, while it received the harshest amounts of damage, it may not have been enough to stimulate compensation.

On the last harvest (25 July) all the treatments yielded around 100 berries and 200 grams. By that time all of the lower order buds (i.e. primaries and secondaries) had matured and the tertiary berries were the only ones left to pick. The primaries and secondaries were the buds that were clipped off in the treatments, and since those were already harvested previously, all of the treatments only had tertiary berries left. Since none of the treatments differed significantly from the control in harvest weights or number of berries on any of the treatments, this shows that compensation in fruit weight is happening to some extent on all harvest dates.

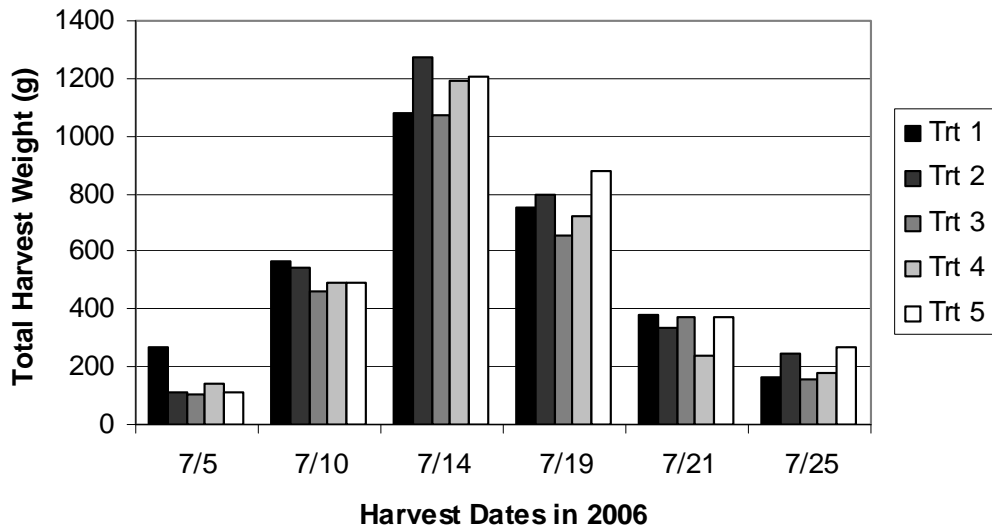


Figure 2.4. Total harvest weights for each treatment at each harvest date.

Treatments are as follows: Trt 1=no buds clipped per cane, and Trt 2, Trt 3, Trt 4, and Trt 5 are 25, 50, 75, and 100 buds clipped respectively per cane.

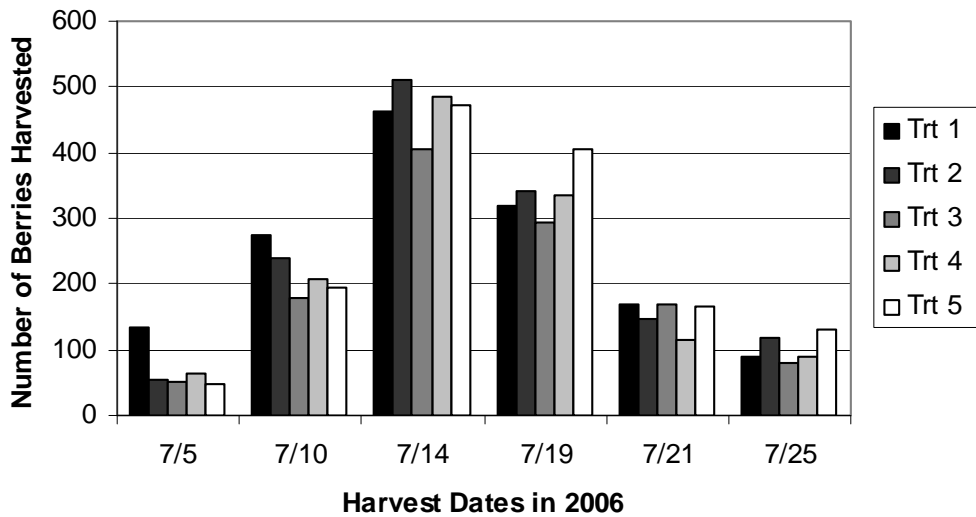


Figure 2.5. Number of berries harvested for each treatment at each harvest date.

Treatments are as follows: Trt 1=no buds clipped per cane, and Trt 2, Trt 3, Trt 4, and Trt 5 are 25, 50, 75, and 100 buds clipped respectively per cane.

In conclusion, the bud clipping treatments did not generate any significant differences in yield from 'Reveille' raspberry. Up to 31% of the flower buds could be removed from canes without having a significant impact on fruit weight, fruit number or fruit size. This suggests the SBW may not present an economic threat to raspberry plantings at this damage level, as the canes appear to be able to tolerate, or compensate for its bud clipping behavior. Clipping buds may have increased fruit set of the remaining buds. So, even though clipped treatments had fewer flowers, more of them were likely successfully pollinated, fertilized, and persisted to harvest. Without actual counts of flower buds before clipping, it is impossible to say if this occurred. Another possibility could be that the clipping treatments induced bud break of additional laterals or higher order buds.

However, cane to cane variation within treatments was very high in regards to yield parameters. Factors such as uneven winter injury throughout the row and different cane positions within a row may also have played a role in each cane's fruiting characteristics if, as a result, some canes were unable to support a typical number of buds and fruit, either as a result of vascular injury or shading, respectively, while other canes were uninjured or not shaded. Waister et al. (1980) studied cane density and found that yield plateaus at a density of 8-9 canes per meter row and that water and mineral nutrition does not seem to play a part in these findings. They concluded that light interception is a critical factor in cane productivity. Wright and Wasiter (1984) also looked at raspberry self-shading as factor of fruiting and found it to be a serious hindrance to total yield for annual and biennial raspberry cropping systems. Finally, the bud removal treatments in this study were all applied at the same time, and relatively early in the flowering period

of the canes, whereas SBW injury would more likely occur throughout the flowering period (Mailloux and Bostanian, 1993), and would likely be heaviest later in the flowering period. Waister and Barritt (1980) found that by removing 50% of the lateral buds on each cane, the remaining nodes produced more fruitful laterals. They also state that if the lateral buds had been removed earlier in the season, before dormancy ended in the early spring, they may have seen even more compensation. Therefore, the ability of canes to compensate for injury may have been less than would have been seen under a typical SBW infestation, as the plants had a relatively greater stimulus and more time to respond.

The control treatment produced the most yield measured in berry weight and number of berries in the first harvest, but by the third harvest, peak harvest, the control had the lowest yield. This suggests that compensation is occurring by stimulating later maturing, higher order flower buds that typically abort, to set fruit.

Raspberries are known to have considerable compensatory abilities when canes are damaged, and it is thought that only a relatively small percentage of flower buds on canes actually produce marketable fruit in a typical season (Braun and Garth, 1984). Removal of flower buds from a raspberry cane, as would be experienced under an infestation of SBW, may have little impact on a cane's final yield and fruit quality. This could be a result of buds forming fruit that typically would have aborted, or simply that high cane to cane variation in raspberry fruiting parameters can mask any differences in yield generated by bud removal, even at relatively high levels. Further bud removal studies which include more cultivars, locations, timings and higher bud removal levels

may illicit damage levels that will suggest appropriate tolerance thresholds for SBW injury on red raspberry.

OBSERVING STRAWBERRY BUD WEEVIL POPULATIONS AND FLOWER BUD DAMAGE IN RASPBERRY FIELDS IN MAINE: ASSESSING THE POTENTIAL CROP LOSS

INTRODUCTION

The red raspberry (*Rubus idaeus* L.) is a high value commercial crop on many small farms in the northeastern United States. Flower buds of this plant are known to be attacked by strawberry bud weevil (SBW), *Anthonomus signatus* Say, a well recognized pest of strawberries (Bostanian *et al.*, 1999; Easterbrook *et al.*, 2003; Khanizadeh *et al.*, 1992; Kovach, 1995; Kovach *et al.*, 1999; Mailloux, 1993; and Pritts *et al.*, 1999), but its economic impact on raspberry is unknown. Strawberry bud weevil is more commonly known as “clipper,” because of the females’ behavior of laying their eggs in flower buds and then severing, or “clipping,” the bud from the plant (Pritts *et al.*, 1999).

Observations by several entomologists (J. Dill, A. Eaton, D. Handley and S. Schloemann) in the region have suggested that SBW may be responsible for raspberry flower bud losses approaching 75% in New England. Yet few growers recognize the problem because the damage occurs early in the season, prior to typical pesticide applications. If raspberries are a preferred host for SBW and flower bud losses resulting from its activity are high, this insect could be causing significant economic damage to commercial raspberry crops. A more complete picture regarding the activity of SBW on raspberry and its impact of raspberry fruit development could help farmers decide when and if management efforts for this insect are needed to prevent significant crop losses.

Surveying raspberry canes for numbers of berries produced or the amounts of yield produced is one way to measure effectiveness of cultural practices used (Orkney and Martin, 1980). It may also be useful in determining how much bud damage each cane

incurred. This SBW damage information about levels of bud damage has not been assessed on Maine raspberries. With this information, growers would know where on the cane the SBW are clipping buds and they could then adjust their cultural practices to lessen the SBW attraction to their crops.

RESEARCH OBJECTIVES

The objectives of this study were to evaluate the efficacy of several different monitoring methods to assess population levels and distribution of SBW in Maine raspberry plantings, and to determine the correlation between estimated SBW sample populations and actual raspberry flower bud damage caused by SBW.

MATERIALS AND METHODS

During the 2005 growing season, the following six monitoring methods were evaluated in raspberry plantings at twelve different locations (Table 3.2, Figure 3.1).

1. Finding clipped buds – Five randomly selected floricanes were selected at five different locations in a field and were examined weekly for the total number of clipped buds per cane.
2. Live SBW- Each flower cluster examined in treatment 1 above was also surveyed for the presence of any SBW.
3. Sweep net – Weekly, in five randomly selected locations in each field, a sweep net was used to sweep the plants at an angle in a continuous up and down “s” motion for ten sweeps over three meters of row. After each three-meter sweep the net was emptied onto a white cloth and live SBW caught were counted. The sweep net has a 1.5 meter long handle, a 0.3 meter diameter opening and a 0.61 meter tapered net.

4. Beat cloth catches – A standard beat cloth (Great Lakes IPM, Inc., 10220 Church Road, Vestaburg, MI 48891-9746) is a white cloth (71 cm square) stabilized by two crossed sticks, which is held by the user adjacent to a raspberry cane. The user hits the opposite side of the cane five times with a piece of PVC piping (3 cm in diameter and 20 cm in length) to dislodge the live SBW from the plant so they fall onto the beat cloth. The number of live SBW that fell onto the cloth was counted. This was repeated weekly in five, different, randomly selected locations at each field.

5. Sticky traps – A sticky trap is a blank, white, cardstock trap (15cm x 23cm) covered in tanglefoot glue, designed for insect collection (Great Lakes IPM, Inc., 10220 Church Road, Vestaburg, MI 48891-9746). Traps were placed 15 meters from the borders of the field and 15 meters apart from each other and from other insect traps in the field. The traps were monitored weekly by counting the number of SBW that got caught on the trap.

6. Sticky traps + pheromone – The sticky traps identical to those described in treatment 5 above were baited with a pheromone capsule pinned to it. The pheromone used was synthesized by International Pheromone Systems, Ltd., Ellesmere Port, Cheshire, England and is an aggregation pheromone for *Anthonomus rubi*, a relative of *A. signatus* with similar hosts and life cycle in Europe. The traps were monitored weekly by counting the number of SBW caught and removing them.

During the 2006 season, the beat cloth treatment (treatment 3) and pheromone treatment (treatment 6) were eliminated from the trial due to the 2005 results of poor correlation between the amount of damage the treatments 3 and 6 predicted and the actual damage in the field.

In 2005, scouting started 3 June 2005 and ended 28 June 2005. Twelve farms were scouted in central and southern Maine (Figure 3.1). In 2006, scouting started 30 May 2006 and ended 29 June 2006. Eleven farms were scouted in central and southern Maine (one farm was dropped from the 2005 list for logistics of scouting in 2006) (Figure 3.1). Each year, all farms were visited once a week for four weeks.

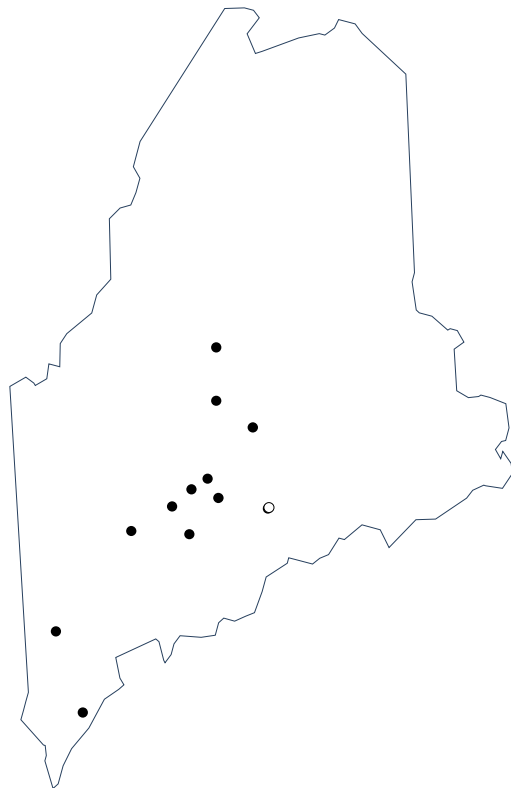


Figure 3.1. Map of farms scouted in 2005 (all marks on the map) and 2006 (only the black filled marks).

In 2005 and 2006, the data for each scouting method was figured at a per-cane basis and was correlated with the actual number of clipped buds found per cane at each farm. The scouting method data (y-axis) was graphed against the actual number of clipped buds (x-axis) and a best fit, linear line was calculated to correlate the amount of

damage found by sampling in the field to the amount of damage actually in the field. As the best-fit line r -value (correlation coefficient) increases, the efficiency of each scouting method in relation to actual clipped buds in the field increases (Table 3.1).

Table 3.1: Correlation coefficient (r) – of different monitoring methods and actual damage derived from bud counts in 2005 and 2006.^z

Scouting Method	2005	2006
# Live Clipper Observed	-0.686	0.098
Sweep Net	0.139	N/A
Beat Cloth	-0.322	0.545*
Clipped Buds Observed	0.628*	0.847***
Sticky Trap Catches	-0.353	0.002
Pheromone Trap Catches	-0.276	N/A

^z*, *** are p-values .05, and .001 respectively

In mid-July, of 2005 and 2006, when the buds had developed beyond the stage of SBW susceptibility (all buds >0.5 cm in diameter), ten canes were cut at the soil surface and removed from each field and brought to the lab. The number of healthy buds and clipped buds were counted on each lateral of each cane. There were on average 32 laterals per cane and the analysis divided the cane into four sections, eight canes per section to determine amounts of clipped buds at low levels verses higher up on the cane. To analyze the relationship between the total number of flower buds and the number of clipped buds per cane, the canes were divided into four sections. Section 1 included the first eight laterals from the ground; section 2 included laterals 9-16; section 3 included laterals 17-24; and section 4 included laterals 25-32. The cane data was analyzed by

general linear model analysis of variance with mean separation by least significant difference tests for each of the sections of the cane and for each year trialed.

SCOUTING RESULTS AND DISCUSSION

The most accurate scouting method for SBW damage in this study was monitoring clipped buds in small field samples (five canes in five locations). Under relatively high SBW pressure in 2006 (Figure 3.2), the correlation coefficient between clipped bud scouting and actual numbers of clipped buds in the field was $r=0.847$, significantly greater than any other method. However, under relatively low SBW pressure in 2005, the r value was only 0.628, which, although no other methods were significantly greater, suggests that under low pressure this method may not accurately represent actual SBW populations (Table 3.1).

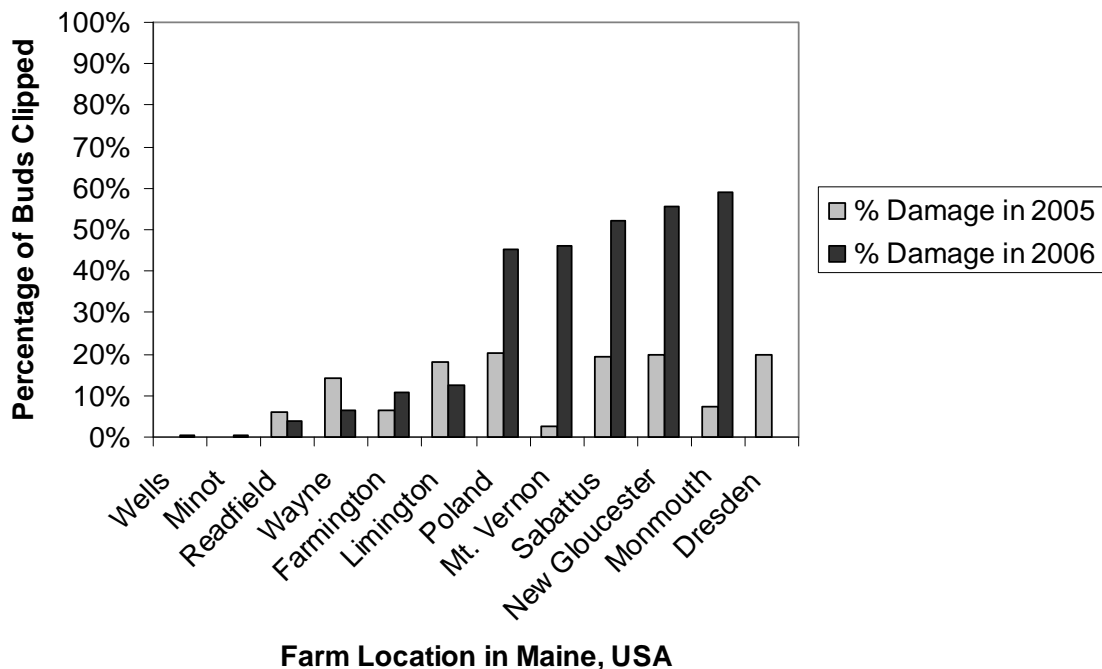


Figure 3.2. The percentage of buds damaged by clippers at 12 Maine farms in 2005 and 2006 with the exception that Dresden was not scouted in 2006.

The sweep net technique was difficult to use in the raspberry planting, caught relatively few SBW, and had very poor correlation with actual bud damage ($r= 0.139$) (Table 3.1). Therefore, this method was not carried forward to 2006.

The sticky traps, with or without pheromone, did not capture enough SBW to accurately represent the amount of clipped buds found in the field. The r value of the sticky traps was only -0.353 in 2005 and 0.002 in 2006, near the lowest of any treatment (Table 3.1). The addition of the aggregation pheromone for *A. rubi* in 2005 had no significant effect on trap captures, and was not carried forward in 2006. The poor correlation with actual bud damage is probably due to the very low numbers of SBW that these traps caught. A single SBW can clip off 75 buds, so only a small number of SBW in a field can lead to high damage levels. Beat cloths caught larger amounts of SBW, but still were not as effective as surveying for clipped buds at determining actual damage levels.

The insect pressure found in 2005 was much lower than in 2006 as was the amount of SBW found in the fields (Figure 3.2). This lower amount of damage and population levels is probably due to uncontrollable environmental factors, including harsh overwintering conditions, and a natural variation in population levels for SBW (Bostanian *et al.*, 1999). Population levels did appear to influence the efficacy of the monitoring treatments tested in this study. Under the higher population levels of 2006, both the beat cloth and scouting for clipped buds had a far higher correlation with actual bud damage than under the low populations of 2005 (Table 3.1).

In 2006, scouting took place over a four week period. The scouting methods that tallied the number of clipped buds and the number of live SBW in the field by hand

surveying found that the peak of the SBW population was the second week of scouting (June 5) in southern and central farms in Maine (Table 3.2). However, there was no difference in numbers of SBW caught with the beat cloth and the sticky trap between each week of scouting, which may indicate further the ineffectiveness of the beat cloth and sticky trap scouting methods since the populations of SBW fluctuated in the field from week to week during the four weeks of scouting.

Table 3.2. Results of scouting methods over the course of a month on a per-cane or per-trap basis in 2006.

Week of	Clipped Buds	Number of live strawberry bud weevil		
		Live SBW	Beat Cloth	Sticky Trap
May 29	0.42b	0.11b	0.35a	0.16a
June 5	3.49a	0.42a	0.36a	0.65a
June 12	1.93ab	0.22ab	0.15a	0.42a
June 19	0.93b	0.15b	0.09a	0.23a
	*	*	NS	NS

^z ‘*’ corresponds to a p-value of .01, ‘NS’ means no significance

Scouting random canes throughout the field sometimes yielded high numbers of SBW and sometimes none, regardless of the scouting method. The insects tended to be concentrated in small groups throughout the field, as Bostanian et al. (1999) found. Therefore, the spatial distribution of SBW in the field appeared to be relatively clumped in this study, but no data was taken to confirm this theory. If this theory holds, it suggests that scouting techniques may need to include samples from many predetermined locations in a single field to accurately represent actual SBW population.

The raspberry plots scouted at each farm were closely examined for similarities that may attract a population of SBW to the raspberries. The first land characteristics examined were the proximity of the raspberry planting from wooded areas and how many sides of the raspberry plot were bordered by woods (Table 3.2). These factors may be important because SBW overwinter at the edges of the woods in the underbrush near their food supply (Bostanian *et al.*, 1999). Therefore, more SBW might have moved into the raspberry crop from the woods to find a mate and a reliable food source. The presence of any wild brambles, the presence and proximity of strawberry plantings and a note of other crops were growing nearby are three more characteristics examined near the raspberry plantings (Table 3.3). Rivard *et al.* (1979) studied SBW movement from strawberry to raspberry crops on Quebec farms and found that SBW appeared in raspberries plantings ten days after they were first found in strawberries. The presence of wild brambles located near the plot was noted as a potential food source for overwintering clippers. However, none of these parameters appeared to show a strong relationship with the amount of clipped buds found at each farm scouted in 2005 and 2006. This could be because the SBW are not moving out of the raspberry planting to the edge of the woods if they find enough food in the raspberry planting when they emerge as adults in the summer. The insects may just stay in the field or right on the outskirts. Another possibility is if the farm has had populations of SBW in the past, they are more likely to have SBW on their crops no matter what crop borders the raspberries or if the raspberry planting is near the woods.

Table 3.3: Raspberry flower bud damage in twelve sites with varying characteristics.^z

Farm Location	Percent Clipped Buds	Feet from Woods	Bordering Woods	Wild Brambles	Strawberry Crops on Farm (feet away)	Other Crops Close By
Wells	0.30%	100	1	1	10	Blueberries
Minot	0.43%	30	3	1	N/A	Blueberries
Readfield*	3.83%	10	4	1	N/A	N/A
Wayne*	6.59%	50	2	0	N/A	Sweet Corn
Farmington*	10.62%	100	1	0	30	Peas
Limington*	12.71%	50	1	1	10	Tomatoes
Dresden*	19.64%	50	2	0	150	Blueberries
Poland*	45.05%	40	2	1	N/A	Sweet Corn
Mt. Vernon	46.26%	50	2	0	20	Blueberries
Sabattus	52.20%	50	1	1	N/A	Tomatoes
New Gloucester*	55.46%	50	1	0	12	Blueberries
Monmouth	59.06%	300	1	1	20	Fruit Trees

^z Scouting observations including how many feet away the raspberry plot is from the woods, how many sides the plot is bordered by woods, if wild brambles are present (1) or not (0) near the plot, if strawberries are on farm and how far away they are from the plot (N/A=not on farm), and other crops located close to the raspberry plot. ‘*’ refers to farms using insecticides to control SBW.

DAMAGE SURVEY RESULTS AND DISCUSSION

Up to 22% of buds on canes sampled in central and southern Maine in 2005 were clipped by SBW, and up to 59% of buds were clipped in those same fields in 2006 (Figure 3.2). This indicates that there is significant SBW damage in Maine raspberry fields and warrants an investigation into developing an IPM program for SBW on raspberry.

The total number of flower buds per cane surveyed at the farms generally ranged between 100 and 300 (Figure 3.3). The number of clipped buds per cane varied greatly between farms and did not have a strong relationship with the total number of buds per cane ($r=0.149$).

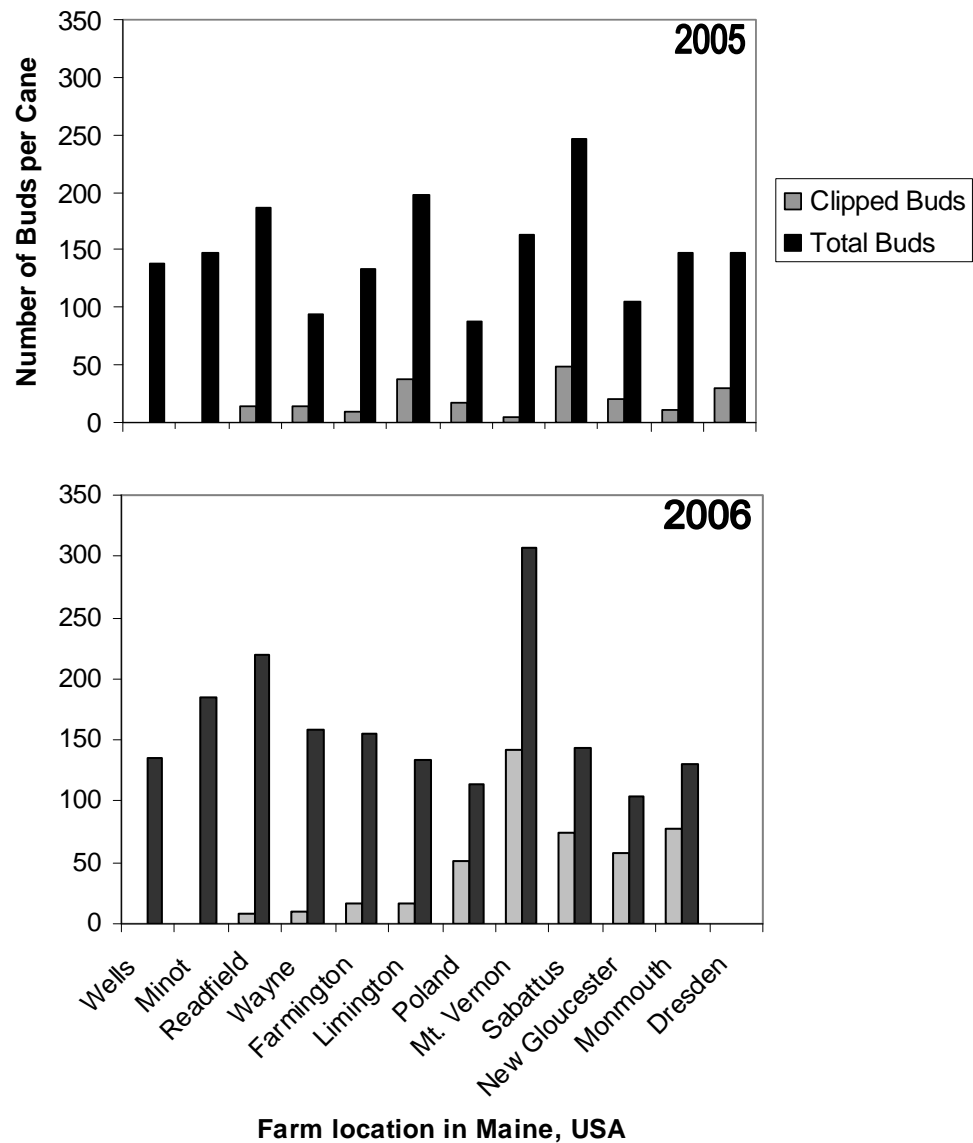


Figure 3.3. The total number of surveyed buds per cane and the number of clipped buds per cane at 12 farms in Maine in 2005 and 2006 with the exception that Dresden was not scouted in 2006.

In 2005, the number of total buds per cane was greatest at the first section (lowest laterals) and was successively lower with each section above. Likewise, the number of clipped buds per cane was greatest in the lowest quarter of the canes, decreased in the next quarter of the canes and decreased again in the top half of the canes (Figure 3.4, Table 3.4).

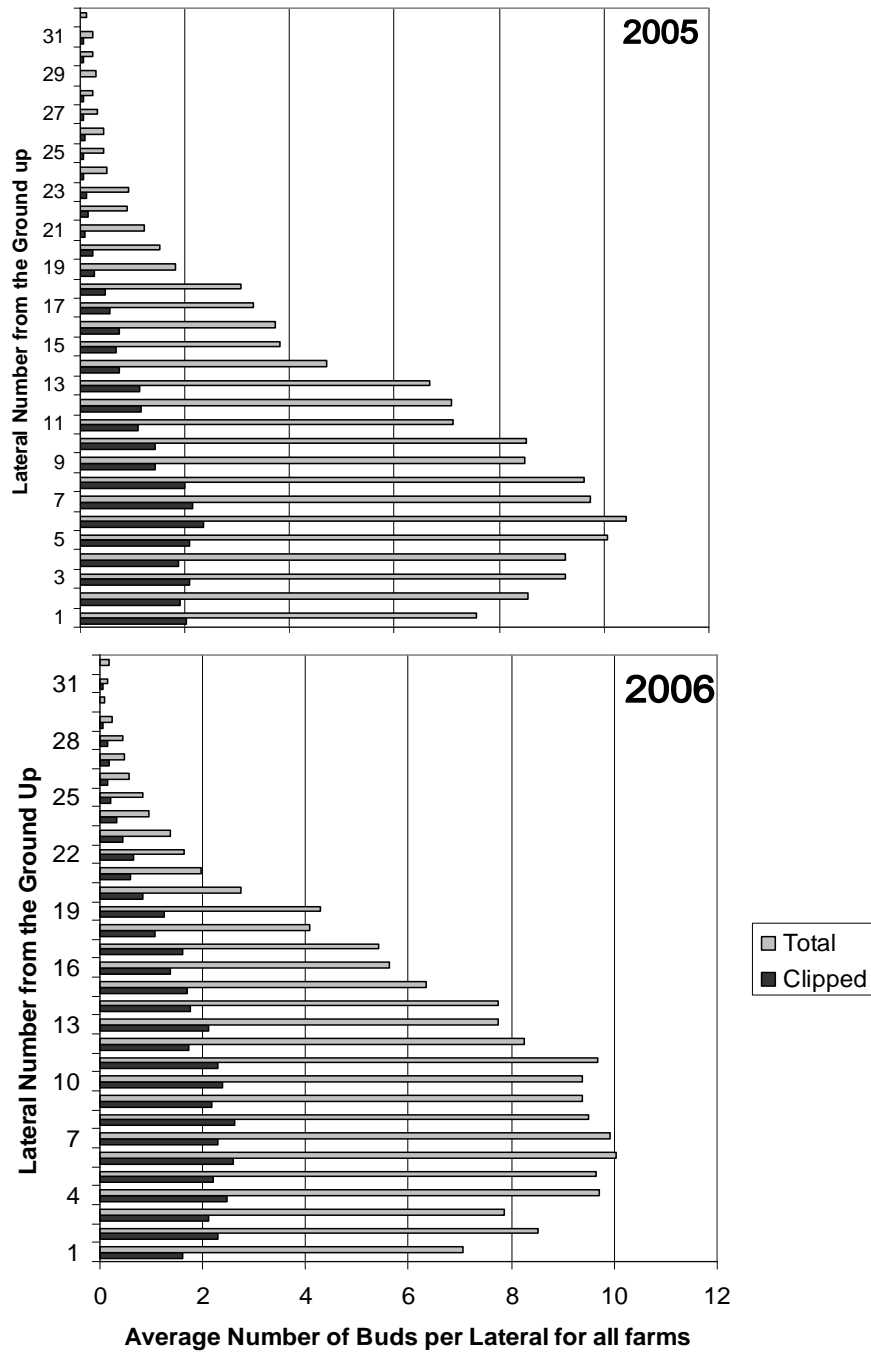


Figure 3.4. The average number of buds (the x-axis), clipped and not clipped, at each lateral of an average raspberry cane (the y-axis) Maine in 2005 and 2006.

The data in 2006 was similar with the highest number of flower buds occurring in lower half of the canes and decreasing numbers on the laterals above. The number of clipped buds per cane followed a similar pattern as the total buds per cane (Figure 3.4, Table 3.4). This data suggests that SBW feed and oviposit throughout the canes, perhaps favoring the lower laterals of the canes somewhat because of the higher number of flower buds associated with them, and the better protection offered by the denser canopy of the lower part of the cane.

The percentage of flower buds damaged in 2005 tended to be greatest toward the bottom of the cane, with the lowest quarter showing the most injured buds. The middle two quarters of the cane had similar damage levels, and slightly less than the lowest quarter. The top quarter of the cane had slightly more injury than the middle two quarters, and slightly less than the lowest quarter (Table 3.4). In 2006, the top half of the cane had the most clipped buds and the bottom half of the cane had slightly less (Table 3.4). Combining both years of data suggests that SBW clipped buds where there were buds to clip (Table 3.5). There were more buds towards the bottom of the cane; therefore, more buds were clipped towards the bottom of the cane. Table 3.5 also portrays SBW as clipping on the top half and bottom half of the cane. There could be several reasons for this. Migration within a cane is likely easier and safer than migration between canes, as shown in *A. grandis* research on cotton (Hardee *et al.*, 1999; Hopkins *et al.*, 1971; Hopkins *et al.*, 1972; and Parajulee *et al.*, 1996), so the insects will potentially concentrate on the buds on one cane before moving on to another cane. Additionally, a single cane offers buds of different developmental stages among its laterals (Crandall,

1995), providing resources for food and oviposition for an extended period of time, reducing any incentive to seek buds on other canes.

Table 3.4. Raspberry cane survey data from 2005 and 2006. Total buds per lateral, total number of clipped buds per lateral and percent clipped verses total buds per lateral in each quarter section of the cane. ^z

Laterals	Total Buds/Lat.		Clipped Buds/lat.		%Damage/lat.	
	2005	2006	2005	2006	2005	2006
25-32	0.3d	0.4c	0.05c	0.1c	18.3ab	28.3ab
17-24	1.7c	2.8b	0.2c	0.9b	14.2b	32.0a
9-16	6.3b	8.0a	1.1b	1.9a	17.1b	24.3b
1-8	9.3a	9.0a	2.1a	2.3a	22.2a	25.1b
	*** ^y	***	***	***	**	**

^z Laterals refers to the number of nodes from the ground up to the top of the cane surveyed. 1-8 comprises the first 8 laterals starting at ground level.

^y ‘***, **’ corresponds to a p-value of .001, .01 respectively

Table 3.5. Raspberry cane survey data combined for 2005 and 2006. Total buds per lateral, total number of clipped buds per lateral and percent clipped verses total buds per lateral in each quarter section of the cane. ^z

Laterals	Total Buds	Clipped Buds	%Damage
25-32	0.3d	0.1d	23.3
17-24	2.2c	0.5c	23.0
9-16	7.1b	1.5b	20.7
1-8	9.2a	2.2a	23.7
	*** ^y	***	NS

^z Laterals refers to the number of nodes from the ground up to the top of the cane surveyed. 1-8 comprises the first 8 laterals starting at ground level.

^y ‘***’ corresponds to a p-value of .001, NS means no significance

The results of scouting for SBW and surveying number of buds clipped suggest that this insect may be an important pest of raspberries in Maine. Up to 31% of buds on canes sampled in this study were injured by SBW and, therefore, would not produce fruit. Sampling canes for clipped buds was the most accurate method to predict potential injury from SBW. Scouting methods that depended on capturing SBW, including sweep nets, beat cloths and sticky traps, did not provide adequate data to predict future injury. Damage surveys indicated that damage caused by SBW is fairly equally distributed over the cane; where there are more buds, i.e. toward the base of the plant, there was more damage. However, SBW populations tended to be clumped in the fields, so high populations in one part of a field may not indicate that the whole crop is in danger. Although, each SBW is capable of producing 75 eggs, therefore, clipping 75 buds. So, a single SBW present in the field could potentially lead to serious economic damage. Accurately predicting SBW injury will likely require a relatively large sample size from each field to overcome this insect's irregular distribution. Although sampling took place over a four week period in this study, using scouting for clipped buds as the monitoring technique would probably allow the timing to be refined to a two week period, beginning when buds reach the susceptible stage.

CONCLUSIONS

Strawberry bud weevil caused up to 59% flower bud damage in the raspberry fields of fourteen farms in central and southern Maine from 2004 through 2006. Five out of eleven farms scouted in 2006 had more than 40% flower bud losses. These data show that raspberries are a suitable host for SBW feeding and oviposition in Maine and suggest that it is a pest of raspberry. However, in the field experiment, 31% of the crop was manually clipped off without reducing yield. However, it has not been determined what level of damage to flower buds is severe enough to impact yield.

Flower bud clipping in the greenhouse experiments devastated crop yields at high levels, although some compensation was observed. At low bud removal levels, there was adequate compensation to make up for yield loss due to clipping. Compensation appeared to be driven by the increased fruit size and/or increased fruit number. The increase in fruit size was mostly found in the lower order berries and the increase in number of fruit was mostly found in the higher order berries. In greenhouse experiment II, clipping all the primary and secondary buds from a plant allowed the tertiary berries to increase in number by 307%, a significant amount to increase, but not enough to compensate for yield losses from clipping. The data from these experiments suggest that raspberry plants have some ability and resources to compensate for flower bud loss. Under high bud loss, the compensation is based mostly on an increase in the number of higher order berries, which may or may not be salable, due to their small size. Compensation was not adequate to significantly alleviate severe reduction in the number of buds.

The most reliable method of monitoring SBW damage in raspberries, with good correlation to the actual amount of bud damage was manually checking five whole canes

randomly chosen in the field for clipped buds. However, the technique is labor intensive and time consuming and, therefore, may not be acceptable among growers.

Although SBW was found in abundance in this study, this does not by itself confirm SBW as an economically important pest of raspberries. From the greenhouse and field clipping experiments and from past research, it is known that raspberry plants are able to compensate for some amount of bud loss. However, the level of clipped buds required to cause economic loss to raspberry crops was not determined from this research, and probably varies by cultivar. This threshold should remain an important objective to determine the importance of SBW on raspberry crops in Maine.

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