Strawberry Cultivars Compensate for Simulated Bud Weevil Damage in Matted Row Plantings

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Abstract. **The strawberry bud weevil (*Anthonomus signatus* Say; clipper) is considered to be a serious early-season pest in perennial matted row strawberry (*Fragaria ×ananassa* Duchesne) plantings in North America. Adult females damage flower buds in early spring by depositing an egg in the bud, then clipping the bud from the pedicel. Action thresholds are low (two clipped buds/meter of row) because pest managers and growers have assumed that one clipped flower bud results in the loss of one average-sized fruit. Fields with a history of clipper damage are often treated with insecticides during the first period of warm weather that coincides with inflorescence development, without scouting for clipped buds or evaluating damage. We examined 12 strawberry cultivars and found that most can compensate for a significant amount of flower bud loss, provided that the loss occurs early in the development of the inflorescence. A new threshold is proposed in which the potential loss of fruit per inflorescence is considered, along with the total number of severely damaged inflorescences. We believe that in most circumstances and with most cultivars, clipper injury will remain below the damage threshold.**

Strawberry clipper or strawberry bud weevil is reported to be the pest of greatest concern during the early pre-bloom season in northeastern matted row plantings (Clarke and Howitt, 1975). The adult female punctures flower buds in early spring as the inflorescences develop, deposits an egg in the bud, then girdles the bud (Neadlee, 1918). Because one female weevil has the capacity to lay many eggs, the clipper is considered to be so threatening that "even a single clipped bud indicates the potential for serious and rapid damage during the next warm spell" (Kovach et al., 1993). Traditionally, fields with a history of damage are treated for clipper during the first period of warm weather that coincides with inflorescence development, even if damage has not been observed. In fields with no history of damage, thresholds are based on the assumption that one clipped bud is equivalent to the loss of one average-sized berry. The conventional action threshold of two clipped buds/meter of row (Kovach et al., 1993) translates into an economic loss of ≈$300/ha at today's prices, assuming a linear relationship between flower number and yield, an average fruit weight of 10 g, and a price of $2/kg. Costs for treating clipper range between $60 and $120/ha, depending on the number of sprays applied (Pritts and Handley, 1988).

When data were being collected from integrated pest management (IPM) implementation projects in the late 1980s and early 1990s, English-Loeb et al. (1999) in New York State noted a lack of correlation between the number of clipped buds and yield. By simulating clipper injury, they were able to demonstrate that cultivars Jewel, Seneca, and Kent could compensate for a large amount of clipper injury by reallocating biomass to the remaining fruit—provided that flower buds were removed early in development of the inflorescence. Data suggested that in these three cultivars, economic loss occurred only if damage was severe or occurred at a later stage of development. The implication from this work is that damage thresholds should be raised well above the current threshold of two clipped buds/meter of row.

Before a recommendation can be made to adjust damage thresholds from current recommendations, it must be determined if the ability to compensate for flower bud loss is a universal characteristic of matted row cultivars. The objectives of this study were to: 1) quantify the compensation ability of 12 strawberry cultivars in matted row plantings and 2) make an informed recommendation for clipper management based on the results.

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Materials and Methods

In 1996, 12 strawberry cultivars were planted in a randomized complete-block design with four replications. Single-row plots were 6 m long, and original plant spacing was 0.5 × 1.25 m. Standard practices were used to establish matted rows (Pritts and Handley, 1998). In May 1997, plots were divided into three 1-m-long subplots. Subplots were assigned one of three treatments: no flower bud removal, removal of all primary flower buds, or removal of tertiary and higher flower buds. Treatments were applied during growth of the inflorescence, as soon as the order of buds could be determined. Simulated clipper injury occurred over a 2-week period, as individual plants and cultivars differed in their rate of development.

In June and July 1997, individual fruits from each subplot were harvested when ripe, categorized into the flower order from which they developed (i.e., primary, secondary, tertiary, and quaternary), and each ordered subset was counted and weighed separately. This process continued until each flower order was represented by at least 50 fruits. At this point, segregation and weighing continued but counting stopped, except for 'Jewel' and 'Seneca'.

The percent change in yield from the removal of the entire order of flowers (primary or tertiary) was calculated from the ratio of treated subplots to the control subplots. However, there was considerable variation among subplots within treatments (CV = 50%). In order to control this variation, an index of compensation was calculated for each cultivar, based on an idealized inflorescence rather than on subplot yields. The index was the ratio of the predicted yield/inflorescence, using average fruit weights from control subplots, to the actual yield per inflorescence, using average fruit weights from flower removal treatments (minus 1.0). For purposes of the calculation, and to control variation, we assumed that a typical inflorescence contained one primary, two secondary, and four tertiary flowers (Janick and Eggert, 1968). For example, nontreated 'Jewel' fruits averaged 19.7, 11.2, and 7.06 g, respectively, for primary, secondary, and tertiary fruit. When the primary flowers were removed from 'Jewel', the secondary fruits averaged 13.1 g and tertiary fruits 8.3 g. Total yield per truss was 59.4 g (2×13.1 g + 4×8.3 g). Expected yield without compensation was predicted to be 50.6 g (2×11.2 g + 4×7.06 g). The ratio of 59.4/50.6 is 1.17. Subtracting 1.0 gives an indication of the percent increase over the control (17%) due to compensation. We also calculated this ratio for the tertiary removal treatment (51.6/42.0) or 1.23 (23%). The average of these two numbers $(17 + 23)/2 = 20$ was our index of compensation for 'Jewel'.

For 'Jewel' and 'Seneca', we calculated the ratio of tertiary and higher order fruits/secondary fruits and compared primary removal plots with control plots to determine if plants also compensated by increasing flower numbers or fruit set.

Results

On average, yields were reduced by only 12% to 14% when all primary or all tertiary buds were removed (Table 1), even though primary, secondary, and tertiary flower orders account for ≈35%, 35%, and 25% of fruit production (by weight) in nontreated inflorescences. Most cultivars exhibited an ability to compensate for flower bud removal. 'Seneca', 'Mohawk', 'Mira', and 'Jewel' exhibited strong compensation, whereas 'Northeaster' did not compensate (Table 1). 'Seneca' yields per truss were not reduced by flower bud removal and the compensation index was very high (44). In contrast, 'Northeaster' and 'Honeoye' produced an average of 30% less fruit with flower removal, and their indices of compensation were low (0 and 5, respectively).

The response to primary flower bud removal did not always parallel the response to tertiary flower bud removal within the same cultivar; but across cultivars, the average percent reduction was similar (11.6% vs. 13.8% for primary and tertiary removal treatments, respectively).

With the exception of 'Northeaster' and 'Honeoye', strawberry plants were able to reallocate between 5 and 14 g of fresh weight among developing fruits in an inflorescence in response to flower bud removal. For example, with 'Jewel', a control inflorescence yielded an average of 73.2 g of fruit, 16.2 g of which was accounted for by the primary fruit. When the primary flower bud was removed, however, the yield per inflorescence was reduced only 6.6 g—less than half of what might be expected from the removal of a 16-g primary fruit. The remaining 9.6 g was reallocated to other fruits.

The number of tertiary and quaternary fruits appeared to increase following primary flower removal. For 'Jewel', the ratio of tertiary plus quaternary fruits to secondary fruits increased from 1.07 to 1.80 with primary flower removal. The ratio increased from 1.69 to 2.19 for 'Seneca', suggesting that some strawberry cultivars also can compensate by increasing flower numbers or fruit set, as well as fruit weight.

Discussion

Our data suggest that with many strawberry cultivars grown in perennial matted rows, the action threshold for strawberry clipper should be higher than the conventional threshold of two clipped buds/meter because most cultivars can compensate for flower bud loss. For example, based on the contribution of primary fruit to total yield in most cultivars, one might expect a 35% reduction in yield from the removal of all primary flowers. Yields, however, were reduced an average of only 12% when all primary flower buds were removed (Table 1).

Even with compensation in yield, a grower might not tolerate removal of primary flower buds since they will develop into the largest fruit, and secondary fruit will not be as large as primary fruit even with compensation. Weevils, however, are less likely to damage primary flowers than other orders simply because there are fewer of them. In fact, recent work suggests that clippers disproportionately select tertiary flowers, regardless of the timing of clipper emergence or the availability of flower buds (Kovach, personal communication). Damage to a limited number of quaternary or tertiary fruit may even be advantageous to the grower because the secondary and primary fruits will become even larger, whereas many tertiary and quaternary fruits are unmarketable because of their small size.

Although strawberry plants may not compensate for flower loss that occurs at a late stage of development (Boyce et al., 1985), English-Loeb et al. (1999) have shown that compensation does occur early in development, although the ability to compensate is reduced over time. Strawberry plants also may compensate for early removal of whole inflorescences (Swartz et al., 1989), suggesting that plants can increase carbon allocation to sinks during bud development if sufficient photosynthate is available.

Several researchers have found evidence of fruit size compensation in strawberry plants. Hohn and Neuweiler (1993) examined 24 cultivars and concluded that large-fruited types are not negatively affected by injury from a related clipper species. Terrettaz et al. (1995) reported that as many as 25% of strawberry flower buds can be removed in established beds without having an economic impact. Khanizadeh et al. (1992) found evidence of compensation in 'Kent' and 'Glooscap'; yields were reduced by only 10% to 12% with primary flower removal, whereas primary fruits account for 25% to 30% of yield in control plants. Clearly, the ability to compensate for loss of flowers is widespread in commercial cultivars, but is not universal. Plant breeders might consider compensation ability in their selection criteria, although we do not know if this ability is heritable. We could discern no pattern based on pedigrees or origin of the examined cultivars.

Determining an appropriate threshold for strawberry clipper will depend on the cultivar and the flower order that is damaged by the weevil. Furthermore, early insecticide treatments for clipper often are associated with two-spotted spider mite (*Tetranychus urticae* Koch) outbreaks later in the season because predatory mites may be killed by the treatment (Kovach et al., 1993). Avoiding a clipper spray could lead to the elimination of miticide sprays later in summer. All three factors need to be considered when developing damage thresholds.

The loss of two flower buds per truss is unlikely to cause a significant yield reduction in most cultivars because the probability of primary bud damage is low, if bud selection is random. Assuming that there are seven flower buds per inflorescence, the clipper has a 14% chance (1/7) of selecting a primary flower bud, but a 57% chance (4/7) of selecting a tertiary flower bud. Should a tertiary flower bud be clipped in a noncompensating cultivar, such as 'Northeaster', the actual loss to the inflorescence would be <10% of the potential inflorescence yield (6.5/69.5 g). Given that there are ≈30 to 70 inflorescences/m in a well-established matted row planting, the loss of two tertiary buds/m would reduce total yield by only 0.3% to 0.7%. This would be difficult to detect statistically, but would theoretically

Table 1. Index of compensation, percent change in yield, and individual fruit weights for 12 eastern strawberry cultivars following primary or tertiary flower bud removal.

				Individual mean fruit weight (g)						
				Primary		Secondary			Tertiary	
Cultivar	Compensation index	% Change in plot yield w/o primaries	% Change in plot yield w/o tertiaries	Control	Tertiary removal	Control	Primary removal	Tertiary removal	Control	Primary removal
Seneca	44	13.0	–1.7	14.2	22.3	9.1	13.3	13.4	5.2	7.6
Mohawk	25	–3.9	10.6	12.2	15.3	7.9	10.9	11.1	6.0	6.8
Mira	25	–16.6	0.9	12.8	15.5	8.7	10.9	10.6	5.1	6.7
Jewel	20	–13.3	–15.9	16.2	25.1	12.3	14.0	15.1	8.1	10.0
Lateglow	14	1.2	–11.3	13.5	17.0	11.1	13.1	11.9	6.8	7.9
Primetime	12	–20.0	–21.5	18.5	20.2	11.5	13.3	13.2	7.5	9.8
Idea	12	–11.1	–5.3	15.4	20.0	13.9	14.4	13.0	8.4	7.8
Earliglow	9	–2.4	–48.9	14.1	14.5	9.7	11.2	10.8	6.2	7.4
Delmarvel	8	–13.2	4.5	14.1	15.1	9.1	11.0	10.1	6.5	6.0
Cavendish	8	–3.9	10.6	20.7	23.7	14.1	14.9	15.1	8.7	10.5
Honeoye	5	–34.0	–33.1	14.4	14.2	9.8	9.4	9.7	6.8	6.7
Northeaster	0	–23.3	–29.0	19.3	17.0	12.1	12.8	11.2	6.5	7.8
SE				1.19	1.62	0.76	0.61	0.98	0.76	0.65

lead to a loss of 100 kg·ha^{-1}. This potential economic loss ($200) exceeds the cost of two insecticide treatments ($120). In this case, the conventional threshold is still appropriate. In a cultivar such as 'Seneca', which can compensate by as much as 14 g/inflorescence, the effect on yield of the loss of one or two tertiary buds per inflorescence would be negligible, and the conventional threshold is not appropriate.

For most of the cultivars we examined, no effect on yield per inflorescence was detected unless the flower bud or group of buds removed would have produced >5 to 14 g of fruit. This phenomenon probably accounts for the lack of a measurable yield response in some cultivars to flower bud removal, even when >50 buds are clipped per meter of row (English-Loeb et al., 1999).

For most cultivars, we suggest the use of a new threshold that counts inflorescences rather than clipped buds. The procedure classifies inflorescences into those that will compensate completely for any flower bud loss (low levels of damage or none), and those that will not compensate completely (high levels of damage). Only those that have high levels of bud loss are counted towards the threshold. On average, a high level of loss would be more than one secondary fruit, or more than two tertiary fruit per inflorescence. If one secondary fruit bud or two or fewer tertiary fruit buds are lost, then the plant will probably compensate for this loss by increasing the size of remaining fruit, so this inflorescence is not counted towards the threshold. If the potential loss exceeds one secondary fruit bud or two tertiary fruit buds per inflorescence, on more than two inflorescences per meter, then a treatment may be warranted. This approach takes into account the compensation ability of cultivars, the order of the damaged flower buds, and the cost of an insecticide application, rather than relying on total numbers of clipped buds per unit length of row to estimate loss.

The threshold we describe could be exceeded by three clipped primary buds per meter, but not by a combination of 30 clipped quaternary, tertiary, and secondary buds per meter. This threshold is slightly more complicated to calculate, but is more realistic than the conventional threshold of two clipped buds/m regardless of order. For noncompensating cultivars, the conventional threshold may still be appropriate, whereas plantings of 'Seneca' may never experience a level of damage that affects yield. Cultivars also may compensate by producing more flowers, but such flowers will probably develop into small, late, unmarketable fruit. We did not consider these fruit in our threshold calculations.

Adjusting action thresholds on the basis of a cultivar's compensation ability should allow pest managers to reduce the use of insecticides and conserve beneficial arthropods. Our experience indicates that in most circumstances encountered by the grower, our proposed threshold will not be exceeded.

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