Research Reports

Moderate Defoliation and Plant Population Losses Did Not Reduce Yield or Quality of Butternut Squash

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Summary. **Butternut squash (*Cucurbita moschata*) plants are susceptible to defoliation and plant population (stand) reduction by insect, disease, temperature extremes, water, hail, or other mechanical damage. The timing of such losses may have variable effects on final fruit quality and yield. The objectives of these studies were 1) to determine the influence of the degree and timing of defoliation and stand reduction on the marketable yield of winter squash; 2) to determine yield compensation after stand reduction and defoliation; and 3) to explore effects of defoliation on fruit total carotenoid content. Experiments were conducted over 2 years in New York and Pennsylvania to explore these objectives. Marketable yields consistently improved with increasing plant population. If population losses occurred while plants were in the rapid vegetative growth phase, the remaining plants responded by increasing fruit number and weight per plant. Plant losses later in the season during fruit enlargement, however, did not elicit the same magnitude of response. Defoliation of 66% leaf area reduced marketable yields, and effects were most severe under high plant populations. Competition among plants restricted compensation. Moderate defoliation (33%) reduced yield in only one of three studies. This level of defoliation also increased the percentage of medium [1.0 to 1.5 kg (2.20 to 3.31 lb)] and large [1.5 to 2.0 kg (4.41 lb)] fruit and decreased the number of jumbo fruit (>2.0 kg). Total carotenoid concentration in mature fruit was unaffected by the defoliation or population treatments. Thus, butternut squash compensated for up to 33% leaf area loss at any time during the season. While the crop could compensate, under some conditions, for up to 50% plant losses, final plant population was more important than the growth stage of damage or defoliation for effects on crop yield.**

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Butternut squash is an important fresh-market and processed crop in the northeastern U.S. This crop is susceptible to defoliation and plant population (stand) reduction by insect, disease, temperature extremes, water, mechanical, and hail damage. The timing of such losses may have variable effects on final crop quality and yield. No research has been published on butternut squash yield responses to stand reduction and defoliation. While information from work on cucumber (*Cucumis sativus*) is available (Widders and Price, 1989), differences in plant growth habit, fruit maturity at harvest, and total yield per plant make inferences across these genera difficult.

Preliminary studies on defoliation of butternut squash at early stages of growth indicated an inconsistent effect on final yield (R. Ayyappath and M. Hoffmann, unpublished data). Removal of 80% of leaf area at the cotyledon, one, two or three-leaf stage resulted in reduced final yields in three years of trials. Loss of 20% to 60% leaf area at these same growth stages had variable effects, depending on the total number of leaves on the plant. The cotyledon stage was consistently the most sensitive to defoliation, as measured by yield losses. In this and other crops, moderate defoliation may increase photosynthetic rates in the remaining leaves, resulting in no observable effect on final yield, or in some cases an overcompensation and increased yield (Pedigo et al., 1986; Wareing et al., 1968). In cucumber, one actively growing fruit may require 40% of the leaf area to support photoassimilate needs (Pharr et al., 1985). A decrease in leaf area during fruit enlargement reduced fruit size and quality of muskmelon (*Cucumis melo* var. *reticulatus*) (Welles and Buitelaar, 1988).

These results suggest an interaction among plant establishment, plant age, and other environmental factors that affect the ability of cucurbits to compensate for leaf area losses at different stages of plant development. The goal of this study was to understand how weather or pest damage to foliage and plant stand may affect yield and quality of butternut squash. The specific objectives were to 1) determine the influence of the degree and time of defoliation and stand reduction on the biological and marketable yield of winter squash; 2) quantify the ability of winter squash to compensate with yields after stand reduction and defoliation; and 3) explore effect of defoliation on fruit carotene content.

Materials and methods

Two experiments (NY-1998 and NY-1999) were conducted at the Homer C. Thompson Vegetable Research Farm, Freeville, N.Y. In 1998, the experiment was planted on an Eel silt loam soil (fine-loamy, mixed, nonacidic mesic Aquic Udifluvent). Preplant fertilizer of 67.2 kg·ha^{-1} (60 lb/acre) of nitrogen (N), 43.7 kg·ha^{-1} (39 lb/acre) of phosphorus (P), and 85.2 kg·ha^{-1} (76 lb/acre) of potassium (K) was applied. Plants were sidedressed with 56.0 kg·ha^{-1} (50 lb/acre) of N as ammonium nitrate, just before vines beginning to run. Plots were sprayed one time with esfenvalerate for control of striped cucumber beetle (*Acalymma vittatum*). Weekly applications of chlorothalonil plus benomyl were initiated at first observation of powdery mildew (*Podosphaera xanthii*) and provided excellent control. Weeds were controlled with two cultivations and by hand as needed. Overhead irrigation supplemented rainfall to provide a minimum 2.5 cm (1 inch) of water per week.

The butternut squash cultivar Zenith (Siegers Seed Co., Holland, Mich.) was selected for the studies based on its vining growth habit and early maturity (80 d from seeding). Transplants were used in Freeville due to historic problems with bird predation of seeds. Transplants were started in the greenhouse on 6 June 1998 and set in the field on 24 June 1998. Plants were established using 1.8 m (6 ft) between rows and 0.6 m (2 ft) between plants in the row. This provided an initial plant population of 8970 plants/ha (3630 plants/acre).

Three factors were evaluated: developmental age at time of damage, plant population reduction, and defoliation, using a split-split plot design with four replications. The main plot treatments were three developmental stages of squash development when defoliation and stand reduction occurred: 1) 4- to 6-leaf stage (young, pre-flowering, 10 July), 2) 8- to 10-leaf stage (vining and flowering, 17 July), 3) 15+ leaf stage (early fruit development and enlargement, 9 Aug.). At each growth stages, plant population (subplot) was reduced by 0%, 25%, 50%, and 75% and the remaining plants were defoliated (sub-subplot) 0%, 33%, or 66%. The final plant populations were 2243 (25% population), 4485 (50%), 6728 (75%), and 8970 (100%) plants/ha (908, 1815, 2721, or 3630 plants/acre). Each subplot was 6.1 m (20 ft) long and included two buffer plants at the ends. Plots with the lowest populations (25%) had two data plants. Yield from individual plants grown at this same population (2243 plants/ha) was confirmed in rows adjacent to the experiment and with the same management, that same year (data not shown).

For defoliation treatments, the actual leaf weight (no petiole) to be removed was determined by sampling five whole plants on the date of treatments and recording complete leaf areas and weights, to develop a model between leaf area and weight (Watson, 1937). Results from the five plants were averaged to determine the weight of leaf area to be removed in each plant to achieve target defoliation levels. Whole leaves were removed and weighed to confirm these defoliation levels. The defoliation effect on final yield of indeterminate tomato did not vary by whole versus partial leaf removal (Stacey, 1983). Mature and expanding leaves were removed at random, to avoid selection of leaves of a specific physiological age and to more closely simulate a weather or pest event.

The fruit were harvested 25 Sept. 1998. Fruit were cut from vines, sorted by size and quality as marketable (free from blemishes or defects) or non-marketable fruit, counted and weighed. Fruit of medium size were analyzed for total carotene content, to determine if defoliation or stand treatments negatively affect nutritional quality. Fruit from four treatment combinations applied at the fruit enlargement growth stage were tested: 0% and 66% defoliation at 25% and 100% stand. Representative fruit were held in cool storage [12.8 °C (55 °F) at 85% relative humidity] until carotene analysis could be completed (about 4 months). Total carotenoids were extracted and determined using official AOAC International methods (AOAC, 1995). Beta-carotene is about 60% of total carotenoids in butternut squash (Manseka, 1997).

A second experiment was conducted at the Pennsylvania State University Russell E. Larson Research Center, Rock Springs, Pa., on a Hagerstown clay loam soil (Typic Hapludalf). Preplant fertilizer of 67.2 kg·ha^{-1} N and 33.6 kg·ha^{-1} (30 lb/acre) K was broadcast and incorporated. Raised beds were formed, drip irrigation tubing buried 5.0 cm (2 inches) deep in the bed center, and black plastic was applied to cover the beds. Rows were spaced 3.0 m (10 ft) apart and seeds were placed at a 0.6-m in-row spacing to produce an initial plant population of 5383 plants/ha (2178 plants/acre). Plots were sprayed twice with esfenvalerate to control cucumber beetle and twice with chlorothalonil or mefenoxam plus chlorothalonil to control powdery mildew. Weeds were controlled with two cultivations before vines running and hand-hoed at early fruit development.

'Zenith' butternut squash was direct-seeded into beds on 5 June 1998. Plant population reduction and defoliation treatments were applied at the vining (8 to 10 leaf) growth stage, on 22 July 1998. A split-plot design with four replicates was used. The final populations (main plots) were 1345 (25% population), 2691 (50%), 4306 (75%), and 5383 (100%) plants/ ha (544, 1089, 1742, and 2178 plants/acre, respectively). Defoliation treatments (0%, 33%, and 66%) were arranged as subplots within population. The subplots were 18.3 m (60 ft) long. Leaf area to be removed was calculated in a manner similar to the Freeville site. Plots were harvested on 6 Oct. 1998 and graded as described for the Freeville site.

In 1999, a third experiment (NY-1999) was conducted at the Freeville site on a Howard gravelly loam soil (loamy-skeletal mixed semic Glossoboric Hapludalf). Raised beds with buried drip irrigation and plastic mulch covering were formed with 1.8 m between beds. This study was designed to further explore effects of defoliation during early plant development, when plants were grown at two populations, 4485 and 8970 plants/ha. These populations were equivalent to the 50% and 100% populations in the NY-1998 experiment. Preplant fertilizer of 46.0 kg·ha^{-1} (41 lb/acre) P and 85.2 kg·ha^{-1} (76 lb/acre) K was applied before forming beds. Nitrogen was applied through the drip irrigation system, biweekly starting one week after transplanting. Four equal applications of 22.4 kg·ha^{-1} (20 lb/acre) N as ammonium nitrate provided a total of 89.7 kg·ha^{-1} (80 lb/acre) of N. Seeds were planted in the greenhouse on 1 June and transplanted to the field on 17 June. Transplants were established at the two population levels, and two defoliation (subplot) treatments (0 and 33% leaf removal) were applied at three growth stages: 3- to 4-leaf stage (30 June), 6- to 8-leaf stage (6 July) and 10- to 12-leaf stage (14 July) using a split plot arrangement with four replications. Plots were harvested 23 Sept. and fruit sorted as marketable or nonmarketable. Marketable fruit were sorted into four size classes, small (<1.0 kg), medium (1.0 to 1.5 kg), large (1.51 to 2.0 kg), and jumbo (>2.0 kg), counted, and weighed. Percentages of fruit within each class were calculated.

All yield data are presented on a per-hectare basis. Analysis of variance was performed on all the data using the SAS package (version 7.0; SAS, Cary, N.C.). Analysis of variance on the effects of plant age and defoliation and linear regression analysis of the plant population data were performed. Orthogonal linear and polynomial contrasts were tested for significance for the defoliation effect in the two 1998 experiments. In the 1999

Table 1. **Effect of population reduction and defoliation at three growth stages of butternut squash on marketable yield, fruit number, and fruit weight when grown in Freeville, N.Y., in 1998.**

Factor	Per ha[z] ($t\cdot ha^{-1}$)	Per ha[z] (no. × 1000)	Per plant (kg/plant)	Per plant (no./plant)	Avg fruit wt (kg)
Plant population [plants/ha (stand %)]					
2243 (25%)[y]	19.4	12.1	8.6	5.4	1.6
4485 (50%)	25.3	16.0	5.6	3.6	1.6
6728 (75%)	29.3	18.5	4.3	2.7	1.6
8970 (100%)	34.9	20.7	3.9	2.3	1.7
Defoliation (%)					
0	29.8	17.9	5.9	3.6	1.7
33	28.6	17.8	6.0	3.8	1.6
66	23.3	14.9	4.9	3.2	1.6
Growth stage					
Young	30.6 a[x]	18.3 a	6.5	3.9	1.7
Vining	28.4 a	18.6 a	5.9	3.9	1.5
Fruiting	22.6 b	13.6 b	4.5	2.7	1.7
Significance $(P > F)$[w]					
Growth stage (GS)	0.049	0.011	0.001	0.001	NS
Plant population (PP)					
Linear	0.001	0.001	0.001	0.001	NS
Quadratic	NS	NS	0.001	0.001	NS
Defoliation (D)	NS	NS	0.021	0.025	NS
GS × PP	NS	NS	0.005	0.005	NS
PP × D	0.014	0.032	0.054	NS	NS
Orthogonal contrasts[v]					
Defoliation	NS	NS	L^{NS}, Q^{**}	L^{NS}, Q^{**}	NS

[z]1 $t\cdot ha^{-1}$=0.45 ton/acre; 1.0 kg= 2.20 lb.
[y]Equivalent to 908 (25%), 1815 (50%), 2721 (75%), and 3630 (100%) plants/acre.
[x]Mean separation within columns for each factor provided when no significant interactions detected. Values followed by the same letter are not significantly different at the 5% level, using Least significant difference test.
[w]The three-way interaction among factors and interaction between growth stage and percent defoliation were not significant for any measurements, and therefore not included in the table.
[v]Orthogonal polynomial contrasts used to test for significant linear (L) or quadratic trends (Q) at 0.05 (*) or 0.01 (**) levels.
[NS]Nonsignificant at $p < 0.05$; P value stated otherwise.

experiment, the effect of defoliation was contrasted with no defoliation, to determine if defoliation had any effect on yield or fruit size distribution. The effect of either no defoliation and defoliation at the 3- to 4-leaf stage (very early) were contrasted with treatments applied at the sixth leaf and later plant growth stages for the same factors.

Results and discussion

Plant population and defoliation. Final plant population and defoliation level affected butternut squash yields and per plant productivity, and significant interactions between these factors were detected. The percentage of marketable fruit did not vary by any treatment in either location, and averaged 95% in Rock Springs, 88% in the NY-1998 experiment, and 97% in the NY-1999 experiment. Increasing plant populations led to significant increases in total marketable yields and fruit numbers in the NY-1998 experiment (Table 1). A significant interaction was detected between the final plant population and the level of defoliation for marketable yield and fruit number (Table 1). The interaction for marketable fruit weight is presented in Figure 1. Fruit numbers data followed similar trends. There were no significant differences between the slopes of the regression models for the control and 33% defoliation treatments but the 66% defoliation treatment had significantly lower slope ($p < 0.001$) (Fig. 1). This indicated that at higher plant populations, 66% defoliation had a greater impact on crop yield. The results from the 1999 NY experiment confirmed the observation of no differences in marketable fruit yield or numbers between the untreated control and 33% defoliated plants, at the 4485 and 8970 plants/ha populations (Table 2).

In Rock Springs, plant populations were lower, due to wider between row spacings. The significant quadratic relationship was detected between marketable yield and plant population (Table 3). As population increased from 1345 (or 25% stand) to 2691 plants/ha (50% stand), yield increased by 28%. Increasing population from 2691 to 5383 plants/ha (100% stand) led to only a 7% increase in yield. Both 33% and 66% defoliation reduced marketable yields ($p < 0.05$) and fruit numbers ($p < 0.0125$) compared with the non-defoliated controls (significant linear orthogonal contrasts, Table 3). As butternut develops, three to eight lateral

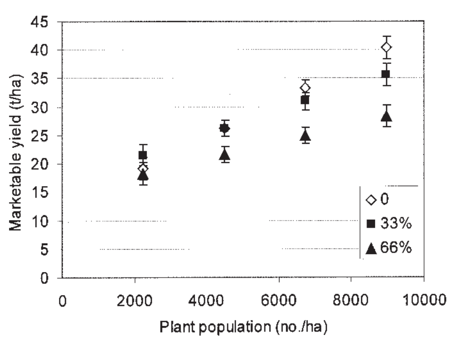

Fig. 1. Change in marketable yield ($t\cdot ha^{-1}$) of butternut squash in response to plant population and defoliation, Freeville, N.Y., in 1998. Final plant populations were 2243, 4485, 6727, and 8970 plants/ha (908, 1815, 2721, and 3630 plants/acre). Plants were not defoliated or defoliated by 33% or 66%. Standard errors are indicated on the chart; 1 $t\cdot ha^{-1}$ = 0.45 ton/acre, 1.0 ha = 2.47 acres.

Table 2. Effect of plant population and defoliation (33%) at three growth stages on marketable yield, fruit number, fruit weight, and fruit size distribution of butternut squash grown in Freeville, N.Y., in 1999.

	Per ha[z]		Per plant		Avg fruit	Proportion of marketable fruit (%)			
Factor	($t \cdot ha^{-1}$)	(no. × 1000)	(kg/plant)	(no./plant)	wt (kg)	Small[y]	Medium	Large	Jumbo
Plant population [plants/ha (stand %)]									
4485 (50%)[x]	29.7	19.8 b[w]	7.5	5.0	1.5	15	38	30	17
8970 (100%)	34.6	24.2 a	4.1	3.0	1.4	19	43	33	5
Significance ($P > F$)	NS	0.049	0.003	0.007	NS	NS	NS	NS	0.054
Stage at defoliation (33%)									
No defoliation	32.2	20.9	4.0	2.6	1.6 ab	12	37 bc	35 a	16 a
3–4 leaf stage	30.1	21.1	3.8	2.6	1.4 b	20	33 c	35 a	11 ab
6–8 leaf stage	32.3	24.4	4.1	3.1	1.3 c	21	48 a	23 b	8 b
10–12 leaf stage	31.3	21.8	3.9	2.7	1.5 ab	14	46 ab	33 a	8 b
Significance ($P > F$)	NS	NS	NS	NS	0.003	NS	0.017	0.028	0.049
Contrasts									
No defolation vs. 33%	NS	NS	NS	NS	0.002	NS	NS	NS	0.013
None/3–4 leaves vs. 6–12 leaves[v]	NS	NS	NS	NS	0.007	0.078	0.003	0.023	0.014

[z] 1 $t \cdot ha^{-1}$=0.45 ton/acre; 1.0 kg = 2.20 lb.
[y] Small = <1.0 kg; medium = 1.0 to 1.5 kg; large = 1.51 to 2.0 kg; jumbo = >2.0 kg.
[x] Equivalent to 1815 (50%) and 3630 (100%) plants/acre.
[w] Mean separation within columns for each factor provided. No significant interactions were detected. Values followed by the same letter are not significantly different at the 5% level, using least significant difference test.
[v] No defoliation or that occurring at the 3- to 4-leaf stage is contrasted with the two defoliation treatments after the 6-leaf stage.
[NS] Nonsignificant at $p < 0.05$; P value stated otherwise.

Table 3. Effect of population reduction and defoliation on marketable yield, fruit number, fruit weight, and percent marketable fruit of butternut squash grown in Rock Springs, Pa., in 1998.

	Per ha[z]		Per plant		Avg fruit
Factor	($t \cdot ha^{-1}$)	(no. × 1000)	(kg/plant)	(no./plant)	wt (kg)
Plant population [plants/ha (stand %)]					
1345 (25%)[y]	12.3	10.9	8.8	7.8	1.1
2691 (50%)	17.0	15.9	6.2	5.9	1.1
4306 (75%)	17.6	17.6	5.1	5.1	1.0
5383 (100%)	18.4	18.5	3.9	4.0	1.0
Defoliation					
0	18.0 a[x]	16.7 a	6.7	6.0 a	1.1 a
33	15.9 b	15.5 b	5.7	5.5 b	1.0 b
66	15.0 c	15.0 b	5.6	5.5 b	1.0 b
Significance ($P > F$)					
Plant population (PP)					
Linear	0.001	0.001	0.001	0.001	0.001
Quadratic	0.001	0.035	0.007	0.035	NS
Defoliation (D)	0.050	0.016	0.001	0.016	NS
PP × D	NS	NS	0.042	NS	NS
Orthogonal contrasts[w]					
Defoliation	L*	L**	L**, Q*	L**	NS

[z] 1 $t \cdot ha^{-1}$ = 0.45 ton/acre; 1.0 kg = 2.20 lb.
[y] Equivalent to 544 (25%), 1089 (50%), 1742 (75%), and 2178 (100%) plants/acre.
[x] Mean separation within columns for each factor provided when no significant interactions detected. Values followed by the same letter are not significantly different at the 5% level, using least significant difference test.
[w] Orthogonal polynomial contrasts used to test for significant linear (L) or quadratic trends (Q) at 0.05 (*) or 0.01 (**) levels.
[NS] Nonsignificant at $p < 0.05$; P value stated otherwise.

branches arise from nodes near the base of the plant. The vines of butternut squash may grow up to 12.2 to 15.2 m (40 to 50 ft) in length, enhancing above ground competition of this crop with high plant populations (Wien, 1997) as well as facilitating compensatory growth when plant population is reduced. The increased competition from higher plant populations and closer between-row spacing (1.8 m) used in both New York studies may have reduced the effect of the 33% defoliation treatment on overall yield, compared with the Rock Springs experiment.

Examination of data on individual plant productivity indicated that increasing population or defoliation reduced the marketable fruit weights and numbers per plant (Tables 1 and 2). A significant interaction suggested that yield compensation after defoliation was greater at lower populations than at higher populations in both sites (Fig. 2). As observed for the per ha marketable yield, a loss of 66% of leaf area always reduced yield and fruit number per plant at both locations, but 33% defoliation reduced yield only in Rock Springs (Fig. 2). In cucumber, as plant population is increased, dry matter allocation to fruit and leaves and the number of fruit developing on branches decreased (Widders and Price, 1989). Thus, final plant population affected the ability of butternut squash to compensate for yields after defoliation. The data from the two sites also suggested about 9.1 kg (20 lb) fruit weight per plant may be a marketable yield maximum for this cultivar when

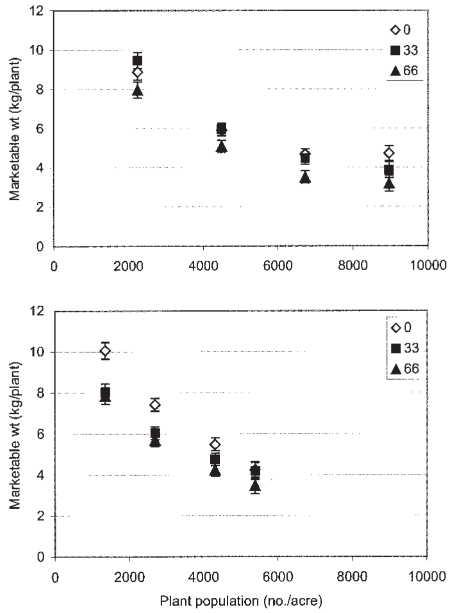

Fig. 2. The change in marketable weight of fruit per plant in response to final plant population and defoliation, for butternut squash grown in (A) Freeville, N.Y., and (B) Rock Springs, Pa., in 1998. Final plant populations were 2243, 4485, 6727, and 8970 plants/ha (908, 1815, 2721, and 3630 plants/acre) in Freeville and 544, 1089, 1742, and 2178 plants/ha (544, 1089, 1742, and 2178 plants/acre) in Rock Springs. Defoliation was applied at 33% or 66% or not at all. Standard errors of the means are indicated on the chart; 1.0 ha = 2.47 acres, 1 kg = 2.2 lb.

grown in the northeastern U.S.

Average fruit weight was not affected by plant population in NY (Tables 1 and 2), but in Rock Springs, fruit grown at the lower plant populations were about 10% heavier than at the other populations (Table 3). Previous research on other cucurbits found no change in average fruit size with increased plant population, including butternut squash (R. Ayyappath and M. Hoffmann, unpublished results), cucumber (Widders and Price, 1989), watermelon (*Cucumis melo*) (NeSmith, 1993) and summer squash (*Cucurbita pepo*) (Brewer et al., 1987), but did reduce average weight of pumpkins (*Cucurbita pepo*) (Reiners and Riggs, 1997). While average fruit weight was not affected by population in the NY-1999 experiment, there was a significant decrease in the percentage of jumbo fruit as population doubled from 4485 to 8970 plants/ha (Table 2).

High plant population and defoliation did not affect the nutritional quality of butternut squash, as determined by total carotene content. Fruit tested from two populations (25% and 100%) and two defoliation levels (0% and 66%) in the NY-1998 experiment averaged a carotene content of 45.4 $mg \cdot kg^{-1}$ (ppm) fresh weight (SE = 8.5). Changes in the percentage of carotene as beta-carotene were not determined.

Plant growth stage. Any damage to plants that occurred during fruit enlargement significantly reduced marketable yield and fruit number per ha compared with damage occurring earlier the season (Table 1). At the young and vining treatment stages, plants were actively growing, but vines had not yet covered the ground and there was minimal above ground competition. Generally, in large-fruited squash plants, leaf area will continue to increase until fruit set, after which the leaf growth rate decreases, as developing fruit become the dominant sink for photosynthates (Robinson and Decker-Walters, 1997). When population losses or defoliation occurred late in the season, the crop was unable to compensate, due to decreased leaf growth rate and high sink demand of existing fruit.

A significant interaction was noted between the growth stage when populations were reduced and the final plant population for marketable weight and numbers of fruit per plant (Table 1, Fig. 3). Only fruit number data are presented since marketable weight per plant followed similar trends. There was no difference in plant productivity if populations were reduced at young or vining stages. However, stand reduction during fruit enlargement significantly reduced fruit numbers per plant (linear $p < 0.005$, quadratic $p < 0.01$). In addition, plants grown at lower populations showed greater yield compensation for stand losses that occurred early in the season than during fruit enlargement. Thus, final population influenced the ability of butternut squash to compensate for stand losses, even when these may occur early in the season.

Unlike plant population, there were no interactions between defoliation and the time when damage occurred (Table 1). Defoliation at vining did not reduce yields more than if damage occurred during fruit enlargement. In the NY-1999 experiment, all defoliations took place during the early growth stages. While there were no differences in marketable yield or fruit numbers, the average fruit weight and the percentages of fruit in different size classes did change as a result of defoliation (Table 3). There were no differences observed between the non-defoliated treatments and defoliation at the 3- to 4-leaf stage treatment. Defoliations during the more active vining stage (after 6 leaves initiated) significantly increased the percentage of medium ($p < 0.003$) and large fruit ($p < 0.023$) and reduced the number of jumbo fruit ($p < 0.014$) compared with the other two treatments (Table 3). This change in fruit size distribution but not total fruit yield suggested that defoliation did not limit carbohydrate production, but changed allocation of carbohydrates across different developing fruit.

In summary, plant population reductions and defoliation of butternut squash impacted the marketable yield, fruit numbers and individual plant productivity, but did not affect fruit carotenoid content. Damage that occurred during fruit enlargement (e.g., late-season hail damage or plant diseases) had greater effect on crop yield than damage early in the season (such as would be observed by insect feeding or poor stand establishment). Plant population was the most important factor governing crop yield, and generally, crop yield was directly proportional to population. If population losses occurred while plants were in the rapid vegetative growth phase, the remaining plants responded by increasing fruit number and weight per plant. This compensation, however, did not always provide yields equivalent to the original population. Often, the damage that reduces plant populations also causes defoliation (e.g., hail). We observed that

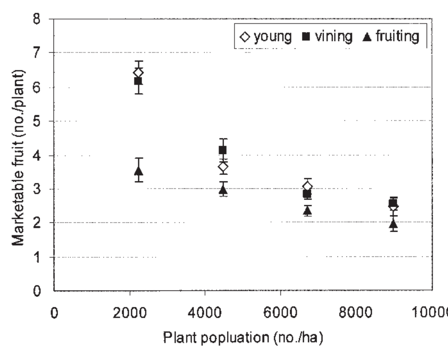

Fig. 3. The change in number of fruit per plant in response to final plant population and timing of plant population reductions, for butternut squash grown in Freeville, N.Y., in 1998. Final plant populations were 2243, 4485, 6727, and 8970 plants/ha (908, 1815, 2721, or 3630 plants/acre). Populations were reduced at three growth stages: young (4 to 6 leaves, preflowering), vining (6 to 8 leaves, flowering) and fruiting (fruit enlarging, 15+ leaves). Mean fruit numbers and standard errors are indicated on the chart; 1.0 ha = 2.47 acres.

defoliation reduced yields to a greater extent under high plant populations. The competition between plants restricted the ability of the plants to compensate for leaf area losses. Interestingly, the crop growth stage when defoliation losses occurred did not affect yields, e.g., defoliation at vining did not reduce yields more than during fruit enlargement. Thus, for growers trying to estimate impact of damage, butternut squash compensated for up to 50% loss of plant population or 33% loss of leaves through increases in individual plant productivity, particularly if damage occurred early in the season. Defoliation under high populations will reduce yields more than at lower populations.

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Economic Evaluation of Mechanized Pruning of Coffee in Hawaii

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SUMMARY. Marketable coffee (*Coffea arabica*) yield and cost of production under two systems of mechanized pruning—hedging and stumping—were investigated. Data were collected from 1997 to 2001—a single pruning cycle—on three cultivars on three farms on Kauai, Maui, and Molokai. Treatments were variations of hedging and stumping, including time of pruning, methods of re-growth control, and tree in-row spacing were applied to each coffee cultivar. Economic evaluation was based on a partial budget analysis of the actual costs per year of the different pruning systems used on each farm. Mechanical pruning costs per acre for best hedging and stumping treatments across cultivars were 90% and 83% less, respectively, than the current practice of manual pruning. Response to pruning system varied according to coffee cultivar, tree in-row spacing and farm location. The tall cultivar Mokka had higher yields when hedged at 5 ft (1.5 m) tall and 5 ft wide, and the semi-dwarf cultivar Yellow Catuai had higher yields when stumped at 2 ft (0.6 m) tall. Hedge pruning should be done early in the year, January to February, for the semi-dwarfs, 'Yellow Catuai' and 'Red Catuai', but can be delayed until May for 'Mokka'. Annual topping in the hedging systems should be done January to May for 'Yellow Catuai' but maybe delayed until May for 'Mokka' and 'Red Catuai' without yield loss. The economic evaluation revealed that the cost of stumping was higher than hedging. For 'Yellow Catuai' on Kauai the economic evaluation indicated that although the cost of stumping was higher, the accompanying higher yields resulted in a higher gross margin for this system. When stumping, vertical branches can be set with a contact herbicide spray to avoid higher hand pruning costs without lowering yields. Stumps should be narrowed after stumping if spaced, 2.5 ft (0.75 m) the current standard in-row spacing for mechanical harvesting. Wide in-row spacing (5 ft) should be considered by growers when planting or re-planting.

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Coffee has been grown in Hawaii for more than 150 years. The Kona district of Hawaii Island is renown for its Kona Coffee. However in the last decade the decreased profitability in the sugar cane production and its consequent decrease in acreage made available agricultural land suitable for coffee on other islands in the State of Hawaii (Cavaletto et al., 1992). The area of harvested coffee on the islands of Kauai, Maui, Molokai and Oahu has increased from 220 acres (89.0 ha) in 1990 to 4,100 (1,659 ha) in 2000 (Hawaii Agricultural Statistics Service, 2001).

In the Kona district of the island of Hawaii the acreage is scattered in small farms, with an average size of 5 acres (2.0 ha) (Hawaii Agricultural Statistics Service, 2001). On the other islands the acreage is represented primarily by a few large farms: Kauai Coffee on the island of Kauai, with 3,400 acres (1,376 ha), Kaanapali Estate Coffee on the island of Maui with 420 acres (170.0 ha), Coffee of Hawaii with 600 acres (242.8 ha) in the island of Molokai, and Waialua Coffee on the island of Oahu with 170 acres (68.8 ha) (Hawaii Coffee Association, 1998.).

These coffee farms having mechanized virtually all production practices including planting, irrigation, fertigation and harvesting represent a new era of coffee production in Hawaii