Nitrogen and Vine-harvest Method Affect Cranberry Vine Production and Yield

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SUMMARY. Four nitrogen (N) rates (0, 50, 100, and 150 lb/acre) were applied annually, and two spring vine-harvest methods (heavy pruning and mowing) were applied biennially in all combinations at one commercial ‘Stevens’ cranberry (*Vaccinium macrocarpon*) farm in southeastern Massachusetts for six consecutive years. Vine weights generated from each treatment combination were collected in Years 1, 3, and 5 (vine-harvest years). Mean vine weight across N treatments from the biennial pruning and mowing events was 1.4 and 3.6 tons/acre, respectively. Vine-harvest method affected yield components (number and weight of reproductive uprights) since mowed plots had values near zero in the vine-harvest year, and pruned vines were always productive. Increasing N rate increased overall vine weight produced. Pruned vines produced more marketable fruit than mowed vines in Year 4 and Year 6. Net income declined with increasing N rate (except Year 1). Averaged over 6 years, increasing N rate decreased net income of and had no effect on pruned and mowed vines, respectively. Although an alternate-year mowing program provides minimal opportunity for sustained vine recovery and would not be recommended for use over an extended period, mowing provided similar net income as heavy pruning (assuming income and/or cost savings from both vines and fruit) when 50 lb/acre N was applied. The incorporation of mowing, in conjunction with other cultural practices that manage the cranberry canopy and generate fruit, can be a viable economic option.

Cranberries are low-growing, trailing, woody vines that, once planted into a commercial setting, could stay in production for more than 25 years. During the productive life of the planting, the vine canopy can become degraded (e.g., too thick to permit good air circulation and light interception, weed populations may increase) and productivity will decline. When the decline in productivity reaches an economic break point, the grower must decide whether to accept the declining yield, renovate and/or replant, or abandon the production area. The high cost of renovation (Cape Cod Cranberry Growers’ Association, 2008) and bed establishment (Sandler et al., 2004) has encouraged

the development of alternative business plan models for Massachusetts cranberry growers. Massachusetts cranberry growers are re-evaluating the traditional use of multidecadal plantings and are incorporating planned renovation and/or replanting every 20 to 25 years into their business plans. For example, growers anticipate replanting about 5% of their acreage each year to maintain the periodicity goal of getting new vines into the ground on a regular basis. The adoption of routinely replanting a portion of the production area each year is driving the present market climate for plant material and indicates that vines

should continue to be in demand for renovation and replanting activities for at least the near future.

Another component of long-term business models under consideration is the use of periodic mowing, which sacrifices the crop in the year of mowing but provides planting material for sale or direct use by the grower who is replanting. In addition to providing vines that could be used to plant new acreage, mowing may offer horticultural benefits including improved canopy architecture that fosters increased air movement and light interception (DeMoranville, 2009). Growers are currently considering and evaluating the costs and benefits of periodically mowing existing beds on their own farms for both economic and horticultural benefits.

Among the benefits may be the substitution of periodic mowing (e.g., every 3 to 5 years) in lieu of the application of sand to the production surface. The application of thin (0.5 to 1.5 inch) layers of sand is a cultural practice, typically performed every 2 to 5 years, to manage the plant canopy as well as suppress insect and weed populations (Franklin, 1913; Sandler et al., 1997). Although sanding is a traditional (>80 years) practice for growers in Massachusetts, NJ, and Wisconsin (Tomlinson, 1937), the benefits of sanding are not always consistent. Sanding can bury horizontal stem (runners) and ultimately encourage reproductive vertical stem (upright) growth that supports more yield output, but in some situations, sanding may decrease canopy light interception and substantially reduce yield (Lampinen and DeMoranville, 2003; Strik and Poole, 1995). Alternatives to sanding are becoming more attractive due to both the high cost of the

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.8824	lb/ft ²	kg·m ⁻²	0.2048
28.3495	oz	g	0.0353
0.9072	ton(s)	Mg	1.1023
2.2417	ton/acre	Mg·ha ⁻¹	0.4461
0.7646	yard ³	m ³	1.3080
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

material (driven up by the demand for sand by the construction industry) and the finite nature of this natural resource (Coastal Zone Management, 2000).

Mowing is used as a horticultural practice for perennial fruit crops and is typically associated with yield reductions. Alternate-year mowing produced the lowest yield in summer-bearing raspberry (*Rubus* spp.) when compared with conventional management and primocane suppression (Nehrbas and Pritts, 1988). When mowing was combined with burning, lowbush blueberry (*Vaccinium angustifolium* and *Vaccinium myrtilloides*) produced higher yields than mowing alone (Kender et al., 1964). When conducted separately, mowing of lowbush blueberry produced lower yield and higher weed populations than burned plots (Smagula et al., 2009). In contrast, preliminary results indicated a positive effect of mowing on flowering of bilberry [*Vaccinium myrtillus* (Marocke et al., 1981)], but there is no indication of furtherance of this work. Anecdotal reports from Massachusetts cranberry growers indicate good responses from mowed vines in terms of fruit production in the year following mowing (M. Beaton, personal communication); crops in the first recovery year have been in excess of 200 100-lb barrels per acre (higher than recent Massachusetts averages). Although mowing does reduce yield in the year of vine harvest, the economics of periodic use of the cultural practice in concert with fruit production in nonmowed years in a high-value crop such as cranberry has not been previously assessed.

Nutrient inputs are important for the recovery and growth of pruned or mowed plants. Pruning and fertilizers interacted to affect lowbush blueberry nutrient leaf content and yield (Warman, 1987). In another study, the application of N in the second year following a pruning event improved lowbush blueberry yield (Penney et al., 2003). Nitrogen is important for cranberry vine establishment and growth (Chandler, 1961; Davenport and Vorsa, 1999; Sandler et al., 2004). Vigorous cranberry varieties ("Stevens") may require between 20 and 60 lb/acre N per year. The economic risks and benefits of annual removal of low levels of vine in combination with various fertilizer regimes for the purpose of

using the vines for replanting a cranberry farm have been recently published (Sandler and DeMoranville, 2009). An objective of the 2009 study was to evaluate upper range and excessive N rates to assess the plant's vegetative response for growers who wished to use portions of their farms as nursery beds for vine propagation. The premise was that high N rates would sacrifice fruit yield; the query was would the vegetative response be great enough to be economically justifiable in certain situations. The present study builds on that work, using the same range of high and excessive N rates in combination with severe methods of vine removal in an alternate-year time frame.

The objectives of this research were to evaluate the effect of N rate on alternate-year pruning or mowing in terms of vine weight harvested and impact on yield components of cranberry, to evaluate economic costs and benefits of these practices, and to develop recommendations for vine propagation and/or fruit production for growers who wish to incorporate periodic vine removal into their commercial farming operations.

Materials and methods

One commercial cranberry farm in South Carver, MA (lat. 41°50'25.58"N, long. 70°43'56.45"W), planted with the variety Stevens, was used in this study. The site was planted in 2000. The soil is described as Tihonet mixed, mesic Typic Psammaquent (U. S. Department of Agriculture, 2008a). The study was randomized complete block design with treatments arranged in a split-plot with five replicates. The vine-harvesting method (pruning or mowing) was the main effect, and N rate (0, 50, 100, and 150 lb/acre) was the sub-plot. Plots were 2 × 2 m²; N plots within a vine-harvest method were separated by 0.4 m, vine-harvest methods within a block were separated by 1 m, and blocks were separated by 2 m. The site was managed as a commercial bed with respect to pest control, irrigation, and frost protection; however, fertilizer was applied according to predetermined research treatments. No other vine removal was performed to any other portion of the bed in which the plots were established.

VINE-HARVESTING METHODS. Commercial growers typically use a ride-on rotating head pruner with

multiple slats with equally spaced knives (Sandler and DeMoranville, 2009) to prune vines; these tend to be machines (e.g., hay balers) that are retrofitted to perform the pruning function and are not available for purchase on the market. In contrast, many models of mowers are available on the market that can be used to mow cranberry vines. Since the research plots were small, typical farm machinery could not be used to apply the treatments. Pruning was accomplished by using hand-held pruning rakes (Hayden Manufacturing, West Wareham, MA). Laborers were instructed to use the rakes with the same intensity as they would when heavily pruning a section of commercial cranberry vines. It was anticipated that the pruning treatment would remove at least 1 ton/acre of vines, which would be higher than that reported in a previous study (Sandler and DeMoranville, 2009), where the highest pruning severity treatment removed 0.54 ton/acre. The present study was designed to complement that work and it was anticipated that the pruning treatment in the present study would represent the next higher step on the pruning severity continuum. Vines were mowed to a height of about 2 cm with a hand-held motorized hedge trimmer. After each biennial vine-harvest event (Table 1), vine clippings from each plot were collected, placed into black plastic bags, and weighed in the field using a hanging digital scale (model 71S-018215; Cabela's, Sydney, NE).

NITROGEN TREATMENTS. Granular formulations of fertilizer for all treatments were applied at both sites in four equal portions (equal four-way split) in all years. The objective was to vary the amount of N applied to the vines while holding phosphorus (P) and potassium (K) applications equal among treatments. Plots designated as 0 lb/acre (0N) received applications of 0N–10.8P–20.8K (0–25–25) for a total rate of 21.6 lb/acre P and 41.6 lb/acre K per year, applied in an equal four-way split. These rates are within the recommended ranges for bearing cranberry vines (DeMoranville, 2010). Nitrogen was applied to the 50 lb/acre N (50N), 100 lb/acre N (100N), and 150 lb/acre N (150N) plots four times at the rates of 12.5, 25, and 37.5 lb/acre, respectively. N rates at the high end or in excess of recommended rates for cranberry

Table 1. Field study information related to dates of vine-harvest treatments, fertilizer applications at four growth stages, upright sample collections, and fruit harvests from a commercial cranberry farm in southeastern Massachusetts.

Yr	Vine harvest treatments ^z	Fertilizer applications				Vine samples ^x	Fruit harvests
		Roughneck ^y	Bloom	Fruit set	Bud set		
2004	5 May	3 June	22 June	20 July	2 Aug.	11 Aug.	14 Sept.
2005	n/a	2 June	7 July	20 July	5 Aug.	17 Aug.	17 Oct.
2006	17 Apr.	23 May	27 June	17 July	16 Aug.	23 Aug.	24 Oct.
2007	n/a	23 May	27 June	17 July	16 Aug.	23 Aug.	15 Oct.
2008	22 Apr.	27 May	25 June	14 July	5 Aug.	26 Aug.	3 Oct.
2009	n/a	26 May	17 June	9 July	6 Aug.	3 Sept.	1 Oct.

^zDate of vine-harvest event and determination of vine weight in the field; n/a = not applicable.

^yGrowth stage describing ≈ 0.5 –1 inch (1.27–2.54 cm) of new growth.

^xSamples collected to assess number and weight of reproductive and vegetative uprights.

production were chosen to force the maximum vegetative response of the plant, knowing that fruit yield would be compromised at these N rates (Davenport, 1996; DeMoranville, 1992; Hart et al., 1990, 1994). Fertilizer was applied using combinations of 20N–4.3P–8.3K (20–10–10), 21N–0P–0K (21–0–0), and 0N–10.8P–20.8K in adjusted proportions so that each plot received the targeted N rate and a total seasonal P and K rate of 21.6 and 41.6 lb/acre, respectively, matching that in the 0N plots. Ammonium–N was the sole source of N in the 21N–0P–0K formulation; the 20N–4.3P–8.3K formulation was 19% mono-ammonium phosphate, 39% urea, and 16% potassium chloride. Triple superphosphate and potassium sulfate were the nutrient sources in the 0N–10.8P–20.8K formulation. Application dates (Table 1) were chosen based on crop phenology (Sandler and DeMoranville, 2008). Fertilizer was spread uniformly by hand across each N plot. Irrigation or rainfall typically followed application within 72 h.

UPRIGHT EVALUATION. To assess the effect of vine-harvest method and N rate on vegetative growth and upright number, vine samples were collected annually in the late summer (Table 1). On every sampling date, one vine sample was collected from every treatment plot by excising all vegetative material at the bog surface within a 28-inch² area. Sampling templates were made by cutting 6-inch-diameter polyvinyl chloride pipe into 1-inch-wide bands. The sampling ring was randomly placed into a plot and positioned as close to the bog surface as possible. Using hand clippers, cuts were made around the entire inner perimeter to permit collection of runners that were passing through the area of the ring. The

uprights were then held together and clipped as close as possible to the bog surface. The samples were placed into small resealable plastic bags and transferred to the freezer for storage at –20 °C until evaluations were performed.

Vine samples were evaluated for various yield components including number and weight of reproductive and vegetative (nonflowering) uprights, as well as runner and total plant dry weight. Uprights and runners were dried for at least 48 h at 60 °C before dry weights were recorded. Total weight was calculated as the sum of vegetative and reproductive upright weight combined with runner weight. Percentage of reproductive uprights was calculated by dividing the number of reproductive uprights by the number of total uprights.

FRUIT YIELD. During each fall, a 1-ft² area was selected randomly for each replicate, and all berries within this area were collected (Table 1). Fruit were stored and evaluated according to previously published protocols (Sandler, 1995). Fruit infected by fruit rot fungi, damaged by insects or physiological causes, or bruised by mechanical means were deemed unusable. Marketable yield was calculated from the weight of all healthy berries collected from the sample area.

ECONOMIC ANALYSIS. The cost of treatments, including equipment and labor costs on a per acre basis were assigned based on information provided by the grower–owner of a local cranberry service business (P. Beaton, personal communication) and from previously published work (Suhayda et al., 2009). The costs for pruning or mowing included the pruning machine (e.g., Hayden pruner, Hayden Manufacturing) or 18-inch head mower (both \$35/h), the buggy to remove

cut vines (\$25/h), an equipment operator (\$35/h), and two unskilled laborers (\$18/h each). Total number of pruned acres per day can vary by desired severity (Suhayda et al., 2009), machine choice, and operator skill and experience. To achieve similar results (i.e., vine removal) as those seen in this study, the owner estimated 4 and 1.5 acres could be pruned or mowed, respectively, in an 8-h period. The total cost was \$1048, and the cost to prune or mow for an 8-h period was \$262 and \$699/acre, respectively. Numbers generated for the economic analysis assumed payment for fruit based on yearly price per 100-lb barrel reports (U.S. Department of Agriculture, 2006, 2008b, 2010) and a purchase price for ‘Stevens’ vines of \$2500/ton (Cape Cod Cranberry Growers’ Association, 2008). Fruit income was calculated from the price per barrel for the years 2004–2009 multiplied by fruit yield (barrels/acre) from each respective year. Income from the generated vines (i.e., money saved from using on-farm vines) was calculated by multiplying the weight of the pruned vines by \$2500/ton (estimated cost of variety Stevens vines). Net income was calculated as the revenues generated from the sum of fruit income plus the vine income minus the sum of the cost of fertilizer and the cost of pruning or mowing.

To generate an economic scenario that would allow a hypothetical comparison of sanding and mowing, fruit and vine income for 2006–2009 at the 50N rate were used as estimates for the mowing values. Estimates for sanding costs were generated by using current labor and material costs and fruit values as follows. Purchase of enough sand to apply 1 inch of sand to an acre at \$12/yard³ would cost \$1608/acre (P. Beaton, personal

communication). Labor estimates (Suhayda et al., 2009) were used to estimate costs for the 2006–2009 time period; \$341/acre was used for labor costs for sanding for a total of \$1949/acre. Fruit production estimates used in the sanding computation were Massachusetts state average values (U.S. Department of Agriculture, 2006, 2010) with an assumption of a 40% decrease in fruit production in the year of sanding (2007) and 20% decrease in the year following sanding (2008) (Lampinen and DeMoranville, 2003; Suhayda et al., 2009).

STATISTICAL ANALYSIS. Data were analyzed with SAS (version 9.1; SAS Institute, Cary, NC). Model assumptions were tested through residual analysis (Shapiro–Wilk statistic), and no transformations were needed. Since the same measurements were collected annually or biennially over a 6-year period, data were analyzed as a repeated measures experiment in Proc Mixed with a compound symmetry model (Littell et al., 1998) for all parameters except number of reproductive uprights per unit area, weight per berry, marketable yield, and fruit and vine income, which used an unstructured model. Responses to vine-harvest method were determined by pairwise comparisons with Student's *t* test, $P \leq 0.05$. Responses to N rate were determined by evaluating linear and quadratic trends from single degree of freedom analysis. Significant levels that could be legitimately tested for best fit were determined by using partitioning of the sum of squares via Slice option in Proc Mixed. Whenever trends were significant, regression equations and coefficients of correlation were calculated. When the interaction of vine-harvest method and N rate was significant, means were separated using Fisher's protected least significant difference at $P \leq 0.05$.

Results and Discussion

SPRING VINE-HARVEST WEIGHT. Spring vine weight was affected by N rate and vine-harvest method ($P < 0.001$), but not its interaction. Trend analysis indicated that the increase in vine weight with increasing N rate was best described by quadratic polynomials ($P \leq 0.040$). An effect of N rate was not seen in Year 1 as the first series of fertilizer treatments were applied after the vine harvest (Table 1;

Fig. 1). Response in cranberry growth to changes in fertilizer regime may not be expressed until the following year (Davenport and Vorsa, 1999), and the response to N rate can be seen in Year 3 and Year 5. In Year 3, vines weight from plots that received 100 and 150 lb/acre N was similar to each and higher than the 0N treatment; the 50N treatment was higher than 0N but lower than the higher N treatments. In Year 5, vine weight from plots that received any amount of fertilizer was similar to each other and higher than the 0N treatment (Fig. 1). At each vine-harvest event, mowing produced significantly more vine weight than pruning (Fig. 2).

Mean vine weight $\pm$ SE (averaged across the three vine-harvest events) for pruning, and mowing was 1.40 ± 0.12 and 3.65 ± 0.22 tons/acre, respectively. These data confirmed that the amount of vine weight removed was sufficient to distinguish between

the treatments; in addition, the pruning treatment was severe enough to remove more vine weight than the highest pruning treatment reported in a previous study (Sandler and DeMoranville, 2009). Of particular interest was the evaluation to see if vine removal with heavy pruning (>1 ton/acre) would more closely approximate yield effects and economics associated with other pruning severities or with mowing.

YIELD COMPONENT EVALUATION. Excessive N is known to cause overgrowth of vegetative plant parts (Davenport and Vorsa, 1999; Eck, 1976) in the form of lengthy runner growth and/or very long uprights (Chandler, 1961). In the present study, the response of weight of vegetative uprights, runners, and total weight to N rate varied by vine-harvest method. In the pruned plots, weight of each parameter (represented by total weight in Fig. 3) was highest

Fig. 1. Effect of nitrogen rate on cranberry vine weight collected from a repeated biennial spring vine-harvest event over a 6-year period (Years 1, 3, and 5), $N = 10$. Vine weights are from whole-plot collections. For each year, means with similar letters are not significantly different using Fisher's protected least significant difference test ($P < 0.05$). Values are mean $\pm$ SE. Regression equations are as follows: $y = -(8.1 \times 10^{-5})x^2 + 0.025x + 0.687$, $r^2 = 0.99$ (Year 3), and $y = -(1.57 \times 10^{-4})x^2 + 0.033x + 2.83$, $r^2 = 0.93$ (Year 5); 1 ton/acre = $2.2417 \text{ Mg} \cdot \text{ha}^{-1}$, 1 lb/acre = $1.1209 \text{ kg} \cdot \text{ha}^{-1}$.

Fig. 2. Effect of biennial spring vine-harvest method (pruning or mowing) over a 6-year period on cranberry vine weight ($N = 20$). Bars within each year with similar letters are not statistically different according to Student's *t* test at $P = 0.05$. Values are mean $\pm$ SE. Vine weights are from whole-plot collections; 1 ton/acre = $2.2417 \text{ Mg} \cdot \text{ha}^{-1}$.

for plots receiving 150 lb/acre N; plots receiving 100 lb/acre N had similar total vine weight as plots that received 50 and 150 lb/acre N (Fig. 3). Pruned plots receiving 0N had the lowest vine weight compared with all other N rates. In the mowed plots, total vine weight was higher in any plot that received N compared with plots that received no N. In addition, irrespective of vine-harvest method, the addition of any N rate increased the number of vegetative uprights (6-year average; Table 2).

It is reasonable to expect that mowed vines would have less vine weight collected from the summer sampling compared with the pruned vines (Fig. 3) since this weight is representative of 4 months of growth recovery from mowed stubble. In contrast, pruned vines retained much of their canopy character and had greater vine weight values overall. Four months after the vine-harvest event, vine weight of mowed vines was similar to or exceeded values typically associated with reasonable vine growth (at least 0.2

kg·m⁻²) on a 2-year-old cranberry farm (Sandler, 2009); vines receiving 100 and 150 lb/acre N exceeded 0.34 kg·m⁻² (data not shown).

In the year of the vine-harvest event, pruned plots had more reproductive uprights, a higher percentage of reproductive uprights, and greater upright (reproductive and vegetative combined) density than mowed plots (Table 2). This is not unexpected as the mowed vines produced extremely few reproductive uprights (i.e., the number of uprights was equal to or close to zero) in the year of the vine-harvest event. However, when vines did produce reproductive uprights (recovery years for mowed vines), the weight, number, and percentage of reproductive uprights decreased as N rate increased. The decline in reproductive uprights with increasing N rate corroborates previous research in cranberry (Davenport, 1996; Eck, 1976; Sandler and DeMoranville, 2009). Since the percentage of reproductive uprights has been shown to be an important yield determinant (Baumann and Eaton, 1986; Eaton and Kyte, 1978), the decrease in reproductive uprights (along with the increase in runners and vegetative uprights) with increasing N rates can help to explain the yield decrease associated with increased N rates noted below.

The guideline goal for total upright density in a mature 'Stevens' planting is 400 uprights/ft² (DeMoranville, 2010); ideally at least 50% of the uprights should be reproductive. In both pruned and mowed plots, values typically ranged from 15% to 30% reproductive uprights (Table 2), with an occasional high-end value of 32% to 38%. All plots receiving the pruning treatment had total upright density values ranging from 310 to 530 uprights/ft² in Years 2 through Year 6 (Table 2). Since mowing reduced the number of reproductive uprights in the year of the vine-removal event, total upright density values were generally below the guideline, ranging between 196 and 340 uprights/ft², and falling below 100 uprights/ft² in 100N and 150N treatments in Year 5.

FRUIT YIELD. Vine-harvest method and N rate affected weight per berry ($P \leq 0.006$); yield responses were affected by the interaction of the treatments ($P \leq 0.002$). Berry weight was significantly higher for pruned vines compared with mowed vines in

Fig. 3. Effect of nitrogen rate on total cranberry vine weight (6-year average) from cranberry vines pruned or mowed biennially and fertilized annually over a 6-year period ($N = 30$). Vine weight estimated from small samples collected randomly from all treated areas each summer (Table 1). Values are means $\pm$ SE. Similar letters within each vine-harvest method are not significantly different according to Fisher's protected least significant difference test at $P < 0.05$; $1 \text{ kg} \cdot \text{m}^{-2} = 0.2045 \text{ lb/ft}^2$, $1 \text{ lb/acre} = 1.1209 \text{ kg} \cdot \text{ha}^{-1}$.

Table 2. Number of vegetative and reproductive uprights collected from cranberry vines that were pruned or mowed biennially (Years 1, 3, and 5) and treated annually with various nitrogen (N) rates for a 6-year period (2004–09) at a commercial cranberry farm in Massachusetts ($N = 5$).

Vine-harvest treatment	N (lb/acre) ^z	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6
<i>Vegetative uprights (no./ft²)^y</i>							
Prune	0	219	140	233	203	231	280
	50	200	184	333	288	309	362
	100	266	166	432	272	270	321
	150	218	172	482	271	382	359
Mow	0	216	200	217	191	195	327
	50	197	277	324	264	197	401
	100	217	178	340	279	90	378
	150	278	259	272	190	46	374
<i>Reproductive uprights (no./ft²)^y</i>							
Prune	0	49	59	77	130	81	156
	50	53	66	162	111	49	170
	100	36	27	39	82	43	151
	150	58	11	21	57	24	71
Mow	0	1	64	1	113	1	117
	50	0	56	0	91	0	73
	100	1	36	0	49	0	22
	150	0	20	0	25	0	20

^z1 lb/acre = 1.1209 kg·ha⁻¹.

^yWhen data were analyzed using repeated measures in a mixed model, probability values for pruning and N treatments were 0.1013 and 0.0103, respectively, for vegetative uprights and 0.004 and <0.001, respectively, for reproductive uprights; 1 upright/ft² = 10.7639 uprights/m².

the year of the vine-harvest event. This is an expected finding as the mowed vines produced extremely few fruit (i.e., zeroes were often entered for this parameter) in the year of the vine-harvest event; when mowed vines did produce fruit, they were of equivalent size to the fruit produced by the vines that were pruned (data not shown). Weight per berry declined linearly with increasing N rate in Year 2 and Year 4 ($P \leq 0.036$), irrespective of vine-harvest method (Fig. 4). High rates of N were mostly associated with decreased berry size but results did vary over the 6-year period; similar variations have been reported previously (Sandler and DeMoranville, 2009). Berry size can be affected by a range of factors besides N rate including pollination, seed number, rainfall, temperature, and general berry health (Cane and Schiffhauer, 2003; DeMoranville and Caruso, 2008; Rigby and Dana, 1971).

It was not unexpected to see yearly fluctuations across a particular treatment in yield (Table 3) since most varieties of cranberry are biennially

bearing (Eaton, 1978; Roper and Klueh, 1994). Weather can also influence the amplitude of the yearly fluctuations (DeMoranville and Caruso, 2008). However, typical yearly fluctuations were magnified in the mowing treatment. The effect of N rate on marketable yield varied by vine-harvest method ($P < 0.001$). The most notable impact of vine-harvest method (which provided the major component of variation associated with the interaction) can be seen in the years of the vine-harvest event (Years 1, 3, and 5); mowed vines produced zero fruit.

To interpret the impact of N rate when both vine-harvest methods produced fruit, the data for the recovery years (Years 2, 4, and 6) were analyzed and the interaction term was not significant. N rate affected yield in all years ($P < 0.022$), and vine-harvest method affected yield ($P < 0.002$) in Year 4 and Year 6. N rate was associated with greater treatment separation with each passing year. In Year 2, treatments receiving 0, 50, and 100 lb/acre N were similar to each

respectively) and had greater yields than plots receiving 150 lb/acre N (0.1 barrel per acre) (Table 3). By Year 6, all treatments differed from each other with the highest yield produced in the plots receiving 0N (211/acre); yield decreased as N rate increased (50N: 167 barrels per acre, 100N: 109 barrels per acre, and 150N: 48 barrels per acre). *t*-Tests indicated that pruned vines produced more fruit than mowed vines ($P < 0.021$) in Year 4 and Year 6 (108 vs. 42 barrels per acre and 165 vs. 102 barrels per acre, respectively).

The effect of severe pruning on yield was more closely aligned with yield responses reported previously with lesser pruning severities (Sandler and DeMoranville, 2009) than with mowing reported in the present study. Even though almost thrice the vine weight was removed by the vine-harvest event in the present study (1.4 ton/acre) compared with the highest pruning treatment in the Sandler and DeMoranville 2009 study (0.54 ton/acre), N rate was the predominant factor affecting yield, not vine removal. Excessive N application (accompanied by excessive vegetative growth) is often inversely related to cranberry yield. Irrespective of vine-harvest method, plots receiving 0N often had the highest numerical yield compared with the plots that received high-end or excessive rates of N.

Previous research indicates that the practice of administering zero N within a commercial farm system would not be sustainable and is not recommended (Davenport, 1996; DeMoranville, 1992). However, although statistically comparable to the amount of fruit produced in the 50N

Fig. 4. Effect of nitrogen rate on weight per cranberry fruit in 2 out of 3 recovery years. Values are mean $\pm$ SE ($N = 10$). Regression equations are as follows: $y = -7.56 \times 10^{-3}x + 1.52$, $r^2 = 0.75$ (Year 2) and $y = 4.14 \times 10^{-3}x + 2.06$, $r^2 = 0.72$ (Year 4); 1 lb/acre = 1.1209 kg·ha⁻¹, 1 g = 0.0353 oz.

Table 3. Marketable yield of cranberry vines that were pruned or mowed biennially (Years 1, 3, and 5) and treated annually with various nitrogen (N) rates for a 6-year period (2004–2009) at a commercial cranberry farm in Massachusetts ($N = 5$).

Vine-harvest treatment	Applied N (lb/acre) ^a	Marketable yield (100-lb barrels/acre) ^a					
		Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6
Prune	0	52.7 a ^b	32.1 a	53.3 ab	200.8 a	120.5 a	259.5 a
	50	34.1 ab	36.9 a	83.4 a	115.2 ab	61.4 b	217.5 a
	100	27.6 bc	25.9 a	21.1 b	89.5 b	22.1 b	143.1 b
	150	13.3 c	0.0 a	33.1 b	25.6 b	16.2 b	40.3 c
Mow	0	0.0 a ^b	27.2 a	0.0 a	84.6 a	0.0 a	162.8 a
	50	0.0 a	23.7 ab	0.0 a	74.9 a	0.0 a	116.1 ab
	100	0.0 a	14.1 ab	0.0 a	4.3 b	0.0 a	74.4 bc
	150	0.0 a	0.2 b	0.0 a	5.2 b	0.0 a	54.7 c

^a 1 lb/acre = 1.1209 kg·ha⁻¹, 1 100-lb (45.4 kg) barrel per acre = 112.0851 kg·ha⁻¹.

^b For each pruning treatment, mean separation within columns using Fisher's protected least significance difference test at $P \leq 0.05$.

plots, the 0N treatment often had the highest yields numerically. This finding seems contrary to expectations based on cranberry research noted above but is similar to that noted in previous work (Sandler and DeMoranville, 2009). This study, conducted at the same location as the present study, examined annual low, moderate, and high pruning with various N rates; N rate was the important factor affecting yield. In 2 out of 4 years, yield was numerically higher in the 0N plots than the 50N plots. Cranberry soils can supply a certain amount of N through mineralization early in the season and uprights can retain a portion of the previous year's N inputs for the current year's use (Davenport and DeMoranville, 2004; Smith, 1994).

A possible explanation of the results might be that the combined pool of N (released, stored, and added) at this site was high enough to cause the yield reduction in the 50N treatment (in addition to the anticipated yield reductions at 100N and 150N). Future pruning work could consider evaluating N rates between 0 and 50 lb/acre N as well as investigate the influence different soil substrates as potential N reservoirs with regards to the short-term and long-term sustainability of fruit and vine yields.

ECONOMIC ANALYSIS. The effect of N rate on fruit and net income varied by vine-harvest method ($P < 0.001$); vine income was affected by vine-harvest method and N rate (both $P < 0.001$). Table 4 presents all

income data (the components that were used to generate net income) in terms of both vine-harvest method and N rate. The planting was 4 years old at the start of the experiment; most cranberry plantings take 4 to 7 years to reach full production. This site would be considered to be a young planting, and it is possible that responses may be different if alternate-year or frequent pruning or mowing were conducted on a more established planting (e.g., more than 10 years old). The increase in yield and income in Years 4, 5, and 6 compared with the first 3 years attest to the attainment of good production on the bed, especially in the pruned plots (Tables 3 and 4). The cyclical bearing patterns of cranberry yield

Table 4. Economic analysis derived from fruit and vine income from cranberry vines that were pruned or mowed biennially (Years 1, 3, and 5) and treated annually with various nitrogen (N) rates for a 6-year period (2004–2009) at a commercial cranberry farm in Massachusetts ($N = 5$). General production costs are presumed equivalent across treatments.

Vine-harvest treatment	Applied N (lb/acre) ^z	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	
<i>Fruit income (\$/acre)^y</i>								
Prune	0	1,692 a ^x	1,156 a	2,055 ab	10,000 a	7,023 a	12,144 a	
	50	1,096 ab	1,331 a	3,202 a	5,737 ab	3,579 b	10,180 a	
	100	886 bc	932 a	813 b	4,458 b	1,289 b	6,697 b	
	150	428 c	0.0 a	1,280 b	1,276 b	943 b	1,886 c	
Mow	0	0.0 a ^y	978 a	0.0 a	4,215 a	0.0 a	7,619 a	
	50	0.0 a	852 ab	0.0 a	3,730 a	0.0 a	5,434 ab	
	100	0.0 a	510 b	0.0 a	213 b	0.0 a	3,480 bc	
	150	0.0 a	9 b	0.0 a	259 b	0.0 a	2,559 c	
<i>Vine income (\$/acre)</i>								
Prune	0	1,675 a	0.0 a	964 c	0.0 a	3,930 b	0.0 a	
	50	1,944 a	0.0 a	1,755 b	0.0 a	6,647 a	0.0 a	
	100	2,324 a	0.0 a	3,083 a	0.0 a	7,493 a	0.0 a	
	150	2,166 a	0.0 a	2,846 a	0.0 a	7,209 a	0.0 a	
Mow	0	7,130 a	0.0 a	2,482 c	0.0 a	9,831 b	0.0 a	
	50	7,035 a	0.0 a	6,940 b	0.0 a	14,936 a	0.0 a	
	100	7,209 a	0.0 a	8,980 ab	0.0 a	14,039 a	0.0 a	
	150	6,150 a	0.0 a	10,434 a	0.0 a	14,307 a	0.0 a	
<i>Net income^w (\$/acre)</i>								<i>Mean (\$/acre)</i>
Prune	0	3,106 a	893 ab	2,757 b	9,738 a	10,691 a	11,882 a	6,511 a
	50	2,752 a	1,041 a	4,668 a	5,448 ab	9,936 ab	9,891 a	5,623 ab
	100	2,894 a	615 ab	3,580 ab	4,142 b	8,466 ab	6,381 b	4,346 bc
	150	2,250 a	-343 b	3,782 ab	932 c	7,809 b	1,543 c	2,662 c
Mow	0	6,431 a	279 a	1,783 c	3,516 a	9,132 b	6,920 a	4,676 a
	50	6,309 a	126 a	6,214 b	3,004 a	14,210 a	4,708 ab	5,761 a
	100	6,456 a	-243 ab	8,227 ab	-540 b	13,286 a	2,727 bc	4,986 a
	150	5,370 a	-771 b	9,654 a	-521 b	13,527 a	1,779 c	4,840 a

^z1 lb/acre = 1.1209 kg/ha⁻¹.

^yAssuming year 1, 2, 3, 4, 5, and 6 payments of \$34.10, \$36.00, \$38.80, \$49.80, \$58.30, and \$46.80 per 100-lb (45.4 kg) barrel (\$1.00/barrel = \$20.00/ton = \$22.0462/Mg), respectively, (U.S. Dept. of Agriculture, 2008b, 2010) and a purchase cost of \$2500/ton (\$2755.78/Mg) for 'Stevens' vines; \$1.00/acre = \$2.4711/ha.

^xFor each pruning treatment, mean separation within columns using Fisher's protected least significance difference test at $P \leq 0.05$.

^wNet income = (revenue from fruit yield + saving from using own vines) - (fertilizer cost + vine harvest costs). Pruning costs = \$262/acre and mowing costs = \$699/acre. Nitrogen costs = \$0, \$27, \$54, and \$81/acre for respective nitrogen treatments.

(Eaton, 1978; Roper et al., 1993) can also be seen in the yearly fluctuations in fruit income for each treatment.

As with yield, the most notable impact of vine-harvest method on fruit income was in the years of the vine-harvest event (Years 1, 3, and 5); mowed vines produced zero fruit. To interpret the impact of N rate when both vine-harvest methods produced fruit income, the fruit income data for the recovery years (Years 2, 4, and 6) were analyzed; N rate and vine-harvest method were significant and the interaction term was not. Fruit income was higher from pruned vines compared with mowed vines in two out of three recovery years. Income was 2.5-fold and 1.6-fold higher from pruned vines than mowed vines in Year 4 and Year 6, respectively; fruit income from the vine-harvest methods was similar in Year 2. Fruit income declined linearly as N rate increased during the recovery years ($P < 0.022$; correlation coefficients ranged from 0.82 to 0.99). A similar linear response was seen in vine-harvest years 1 and 5 ($P < 0.001$, $r^2 = 0.97$ and 0.90 , respectively); the trend in Year 3 was also linear but not significant ($P = 0.058$).

Vine income fluctuated on a forced biennial cycle since income was only generated in the vine-harvest years (Years 1, 3, and 5). In vine-harvest years, mowed vines generated more income than pruned vines ($P < 0.001$) since mowed vines generated 2.0- to 4.2-fold more vine weight than pruned vines (Fig. 2; Table 4). Increases in vine income as N rate increased were best described by quadratic polynomials in Year 3 and Year 5; N rate had no effect in Year 1. The lack of N rate effect in Year 1 was expected as no fertilizer treatments had been applied at the time of the vine harvest in the early spring (Table 1).

The data from net income provides information related to the potential risk-benefit of cycling between alternating the generation of income from vines and fruit (Table 4). As would be expected, net income is higher for mowed vines in the vine-harvest years ($P < 0.001$) and for pruned vines in the recovery years ($P < 0.021$). However, the differences in net income during the recovery year became smaller as the 6-year study progressed; pruned vines produced 4.6-fold, 2.7-fold, and 1.6-fold more income than mowed vines

in Year 2, 4, and 6, respectively. Increases in net income from mowed vines were more consistent over the course of the study being 1.2-fold, 0.8-fold, and 1.4-fold higher than pruned vines in Year 1, 3, and 5, respectively. When averaged across the 6 years (and across N rate), there was no difference in net income between the two vine-harvesting methods (prune: $\$4785 \pm \$372/\text{acre}$ and mow: $\$5066 \pm \$449/\text{acre}$).

Averaged over 6 years, increasing N rate had no effect on net income of mowed vines and decreased net income from pruned vines (Table 4). Irrespective of vine-harvest method, net income declined linearly in Years 2, 4, and 6 (recovery years) ($P < 0.015$, $r^2 = 0.84$, 0.99 , and 0.99 , respectively) and were best described by quadratic polynomials in Years 3 and 5 (vine-harvest years) ($P < 0.043$, $r^2 = 0.96$ and 0.61 , respectively) with increasing N rate. Although the 0N treatment produced comparable yields and income to the 50N treatment over the 6-year period, using 0N inputs is not recommended to sustain long-term productivity of a perennial crop (Davenport, 1996; DeMoranville, 1992). In addition, the high-end N rates (100N or 150N) used as treatments in this study would not be practical nor recommended for a commercial cranberry farm. The data do not indicate any additional benefit from applying more than 50 lb/acre N. In fact, future research may show that N rates between 0 and 50 lb/acre N may provide the best economic return on vine-harvest beds.

The most recent estimate on the cost of production for cranberry is about $\$4100/\text{acre}$ (First Pioneer Farm Credit, 2008). All treatments in the present study except pruning with 150 lb/acre N surpassed the cost of production per acre (Table 4), garnering a net profit for the grower. Larger farms are able to distribute capital costs over a larger number of acres and typically have more efficient utilization of labor resources than smaller farms. Consequently, a Massachusetts cranberry company farming more than 1400 acres reported their costs to be $\$3200$ to $\$3300/\text{acre}$ in 2006 and 2007, respectively (Suhayda et al., 2009). At 50 lb/acre N, the efficiency of scale for a large farm would mean a profit of about $\$2500/\text{acre}$ (pruning or mowing)

compared with about $\$1600/\text{acre}$ for a small farm. Costs can also vary by region; in 2006, the production of one barrel costs $\$17.00$, $\$20.12$, $\$23.39$, $\$28.66$, and $\$55.85$ for New Jersey, Wisconsin, Massachusetts, Oregon, and Washington, respectively (First Pioneer Farm Credit, 2008). These regional and farm variations must be considered when calculating the risk-benefit of a cultural practice.

In the year of vine harvest for a mowed farm, a grower could capture additional savings relating to the tasks of frost protection, harvest, and pest management. The first two activities would not have to be performed, and pest management efforts could be curtailed in the year of mowing. Growers should still scout mowed farms and make any necessary management decisions based on that information. Energy cost savings associated with frost protection activities could fall in the range of $\$300$ to $\$400/\text{acre}$ (First Pioneer Farm Credit, 2008) with additional savings coming from reduced worker overtime hours. Costs associated with harvest operations can be variable depending on crop load and labor expenditures, but a good yielding farm (e.g., 250 barrels per acre) had a harvest labor value of $\$800/\text{acre}$ in 2008 (P. Beaton and C. DeMoranville, personal communication). A 50% reduction in pesticide use would save an additional $\$110/\text{acre}$ (First Pioneer Farm Credit, 2008). Taken together, an additional savings of about $\$1200/\text{acre}$ could be realized in the year of mowing.

For growers who are planting the newest varieties currently available (e.g., Crimson Queen, Mullica Queen) on their own properties, additional savings could also be realized as unrooted vines (propagated from on-farm nursery beds) could be conventionally planted using a disc with multiple rotating heads. This would be in lieu of purchasing stolons and/or rooted plugs from commercial sources. The purchase of rooted cuttings for planting currently ranges between $\$8300$ and $\$11,800$ per acre (Integrity Propagation, 2009). The purchase of a sufficient quantity of stolons (to provide the recommended rate of 43,560 plants per acre) costs $\$2400$ per acre. According to current licensing agreements, growers may plant unrooted vines on their own farm but may not sell vines to other

growers or parties; repeated mowing or pruning events by the grower who has the license are permitted, but any plant material that is generated must be used on-farm or disposed of appropriately (N. Vorsa, personal communication). These use patterns need to be considered in the development of a business plan that includes the new hybrid varieties.

Another advantage to on-farm propagation would be the maintenance of genetic purity. As the bed ages, runners may be more likely to arise from off-type vines (i.e., less genetically similar to the originally planted vines) from seeds deposited on the production floor. Data also suggest that genetic impurity tends to increase with each successive bed planted from cut vines (K. Patten, unpublished data). Since mowed vines from a nursery bed would be of stable genetic purity, they could likely command a higher price on the market.

Alternate-year vine harvest was judged to be the shortest time interval that a grower would realistically consider using for vine propagation and was included in this experimental design to test cranberry vine resilience under extreme conditions. Alternate-year vine harvest would not be recommended as general practice on a commercial scale. It is anticipated that growers would incorporate vine-harvest removal (i.e., severe pruning or mowing) into their operations on an occasional basis (e.g., every 3 to 5 years). This would place vine harvesting into the same periodicity as sanding. If a grower had long-term, substantial need for vines, a more practical approach might include the designation of several beds for nursery propagation with a rotation of vine removal occurring among these beds. This would alleviate any physiological stress associated with repeated, short-interval vine harvests and promote long-term sustainability of the production bed. Maintenance of genetic purity could serve as a reason to shorten the interval between mowing events (i.e., limiting the opportunity for runners to arise from deposited fruit) but would still likely not warrant an alternate-year approach. Future work could investigate the economics and plant response of various vine-harvest intervals that more closely approximate the frequencies that would be used in commercial operations.

Using the combination of actual data from the present study (Table 4) with economic assumptions from the U.S. Department of Agriculture data (see Materials and Methods), the substitution of mowing for periodic sanding is certainly competitive with the income derived from sanding. In the present scenario, mowing provided a greater net income than sanding (\$7061 vs. \$5468/acre), assuming that the mowed vines are used on-farm (cost savings) or sold off-farm (additional income). Yield reduction due to sanding will vary depending on thickness of the sand layer (i.e., yield reduction increases as the depth of the sand deposited increases) (Lampinen and DeMoranville, 2003; Suhayda et al., 2009) and the accuracy of the sand deposition (Hunsberger et al., 2006); the accuracy and impact of the sanding practice will affect the actual net income generated. Both methods decrease yield but sanding has other undesirable consequences such as decreased canopy light interception and decreased anthocyanin content (Lampinen and DeMoranville, 2003; Suhayda et al., 2009).

From a horticultural perspective, alternate-year or occasional mowing in cranberry production systems may also provide benefits such as uniform canopy structure, a desirable characteristic in cranberry production. In pastoral systems, mowing had a positive effect on plant canopy architecture by providing increased density and symmetry of tall fescue [*Festuca arundinacea* (Rolhauser et al., 2007)]. The impact of mowing on pesticide use, particularly against fruit rot organisms that thrive in moist dark environments (i.e., a suboptimal canopy environment), and its impact on cranberry fruit quality and vine canopy architecture are areas worthy of future research. Mowing may provide a sustainable alternative to sanding, especially when used in concert with other pest management and horticultural practices that take advantage of improved canopy air circulation and light interception as well as the economic advantages afforded by alternate-year vine and fruit production.

Conclusions

The integration of nontraditional (for cranberry production) horticultural methods may provide sound business plan alternatives for cranberry

growers. Even though fruit is sacrificed in the vine-harvest year, sale of vines or cost savings (if growers do not have to purchase vines to replant portions of their own farms) associated with mowing can be profitable and comparable to net incomes derived from heavy pruning that have yearly fruit incomes. Many variables can alter the bottom line for any farmer who engages in these practices. However, in this study, a bed that annually received 50 lb/acre N and produced 4 tons/acre of cranberry vines per year in three vine-harvest years (on an alternate-year cycle) and 100 barrels/acre per year in three recovery years generated a yearly average of almost \$5800/acre. If the cost of production is \$4000/acre (First Pioneer Farm Credit, 2008), growers can anticipate an overall net profit of \$1800/acre. If the demand for vines exceeds the supply and keeps prices around \$2500/ton (or if growers continue to need to generate their own vines), vine income will contribute a greater proportion to net income than fruit income on mowed cranberry farms.

In the present study, cranberry was able to recover from and sustain adequate regrowth from three sequential biennial mowing events. Although alternate-year mowing was economically competitive for the scenario described above, it is anticipated that growers would use longer intervals between vine-harvest events on the same bed to minimize physiological vine stress and promote the long-term sustainability of the bed. In addition, occasional mowing would more closely approximate the interval currently used for sanding the production surface and mowing could be easily transitioned into management plans. If aiming to achieve a specific goal, alternate-year vine harvesting could be used on the same bed for a short time frame, but would not be recommended on a continual basis. Horticultural and pest management benefits from alternate-year or occasional mowing need to be more fully investigated. If the canopy architecture is improved enough to increase air circulation and light interception, alternate-year or occasional mowing may also provide an opportunity to reduce pesticide inputs into the cranberry production system.

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