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Economic Comparison of Initial Vine Density, Nitrogen Rate, and Weed Management Strategy in Commercial Cranberry

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SUMMARY. A 2-year field trial examined the interaction of nitrogen rate, vine density, and weed management options for establishing new cranberry (*Vaccinium macrocarpon*) plantings. Utilizing the vigorous hybrid, 'Stevens', the cost-efficiency of the treatment combinations was evaluated by combining cranberry and weed biomass data with various economic estimates. The most cost-effective production scheme for establishing new cranberry beds is to plant vines at a low density, use moderate rates of nitrogen, and apply an annual application of a preemergence herbicide. This combination produced substantial vine coverage at very low cost, reduced weed biomass by 85% compared to untreated plots, and gave the best weed control per dollar spent. Growers may opt for other reasonably successful combinations that involve higher labor costs if they can produce their own cuttings (reducing initial costs) or if they are farming with the intent to reduce overall synthetic inputs.

The establishment of a new planting and its associated activities are among the most expensive operations performed by cranberry growers. The actual cost of a complete renovation project, depending on access to local materials, equipment, and labor, can range from \$24,710/ha to \$61,774/ha (\$10,000/acre to \$25,000/acre) (L. Reno, personal communication). Typical activities include removal of existing vines by bulldozer, laser leveling of the bog surface, addition of a deep sand layer about 10 to 20 cm (3.9 to 7.9 inches), fumigation, repairing or replacing irrigation systems, purchasing and planting of new vines, and the application of fertilizers and herbicides (DeMoranville et al., 1996, 2001). Renovated areas are usually fumigated with either dazomet (Basamid; BASF Corporation, Research Triangle Park, N.C.) or metham (Vapam; Amvac Chemical Corporation, Los Angeles, Calif.) prior to planting. Vines are typically planted at densities between 2.2 to 4.5 $\mathrm{Mg \cdot ha^{-1}}$ (1 to 2 ton/acre), depending on cost and availability. Napropamide (Devrinol; Syngenta Crop Protection, Inc., Greensboro, N.C.) is the recommended preemergence herbicide for new plantings (DeMoranville et al., 2001). The substantial financial and time investment associated with the establishment of a new cranberry bed mandates that the grower maximize vine colonization and minimize the effects of weed competition.

Growers must make choices regarding planting density, nutrient management, and pest management when establishing a new planting. Combining biological and economic data to evaluate the success of new plantings has not been previously examined. What is the most economical combination of nitrogen rate, vine density, and weed management that provides satisfactory ground coverage? Are postemergence weed options worth the extra labor costs, especially for growers who opt for organic production? The objective of this study was to use data from recent field research, along with various economic parameters, to evaluate the cost effectiveness of various vine densities, nitrogen rate, and weed management schemes for cranberry bed establishment.

Materials and Methods

FIELD STUDY INFORMATION. Data used in this economic analysis were taken from a field study conducted in 2000–01 at the University of Massachusetts State Bog, East Wareham, Mass. (Sandler, 2004). About 0.2 ha (0.49 acre) of cranberry bog was scraped and leveled in Fall 1999. During the leveling process, about 15 cm (5.9 inches) of coarse sand was applied to the surface. The fumigant, dazomet, was applied on 29 Oct. 1999 at 332.9 $\mathrm{kg \cdot ha^{-1}}$ (297 lb/acre) a.i. Freshly cut (nonrooted) 'Stevens' vines, ranging in length from 15 to 40 cm (5.9 to 15.7 inches) were obtained from local commercial growers. The vines were spread by hand and disked into the

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sand by a commercial planting machine on 4 May 2000. Vines were fertilized with 112.1 kg·ha^{-1} (100 lb/acre) triple superphosphate (0N–19.8P–0K) and irrigated as recommended for new cranberry plantings (DeMoranville et al., 2001).

Though not technically a measure of plant density (i.e., no. plants/unit area), the term vine density is commonly used in commercial cranberry production to denote the amount of vine cuttings applied to an acre (DeMoranville et al., 2001; Strik, 2002). The following treatments were included in all combinations: 1) four nitrogen rates: 0, 28.0, 56.0, and 112.1 kg·ha^{-1} (0, 25, 50, and 100 lb/acre); 2) four vine densities: 0, 1.8, 3.6, and 5.4 Mg·ha^{-1} (0, 0.80, 1.61, and 2.41 ton/acre) of the hybrid cultivar, Stevens; and 3) three weed management options: application of a preemergence herbicide, postemergence control, and no weed control (untreated). The experiment was replicated four times in a randomized-complete-block-split-split-plot design (Fig. 1).

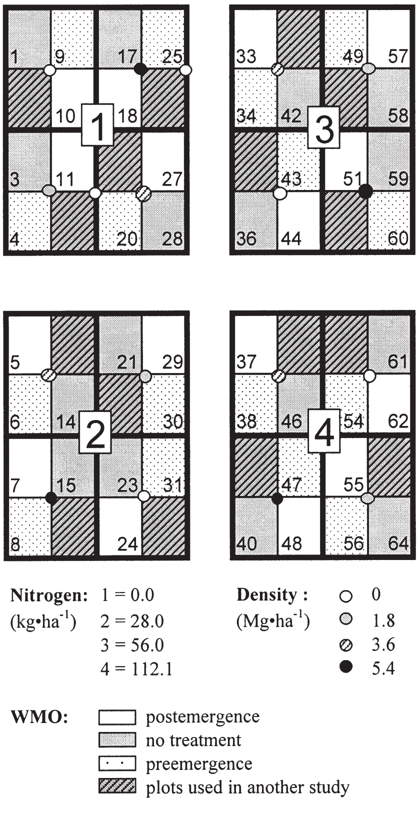

Fig. 1. Schematic of experimental plot design showing all combinations of four nitrogen rates, four planting densities, and three weed management options (WMOs). One replication is shown in full; 1.0 Mg·ha^{-1} = 0.45 ton/acre, 1.0 kg·ha^{-1} = 0.89 lb/acre.

Abbreviations have been used to simplify expression of treatment effects and their interactions. For the purposes of the subsequent discussion, the following abbreviations may be found in the text:

N = nitrogen rate
WMO = weed management option
D = vine density
Zero-N = 0.0 kg·ha^{-1}
Low-N = 28.0 kg·ha^{-1}
Med-N = 56.0 kg·ha^{-1}
High-N = 112.1 kg·ha^{-1}
Zero-D = 0 Mg·ha^{-1}
Low-D = 1.8 Mg·ha^{-1}
Med-D = 3.6 Mg·ha^{-1}
High-D = 5.4 Mg·ha^{-1}
Pre = preemergence treatment
Post = postemergence treatment
Unt = untreated control

Abbreviations for treatment combinations are listed by split-plot order when appropriate and separated by slashes, e.g., Low-N/Zero-D/Pre-WMO.

In both 2000 and 2001, nitrogen was applied in five equal doses of 5.6, 11.2, and 22.4 kg·ha^{-1} (5, 10, and 20 lb/acre), alternately as urea (46N–0P–0K) or as a complete NPK granular fertilizer proportioned as 19N–8.2P–15.8K. With the latter fertilizer, nitrogen was applied in the ammoniated form, as cranberries preferably take up nitrogen in this form (Greidanus et al., 1972; Rosen et al., 1990). Using a biweekly schedule where nitrogen sources were rotated, urea was applied on 30 May, 26 June, and 24 July 2000, and the NPK fertilizer was applied on 13 June and 11 July 2000. Similarly, urea was applied on 14 May, 14 June, and 12 July 2001, and the NPK fertilizer was applied on 29 May and 27 June 2001. Fertilizer was spread uniformly by hand across each nitrogen plot. Irrigation or rainfall typically followed application within 72 h. During each of the initial 2 years of vine establishment, the total nitrogen applied to each plot was 0, 28.0, 56.0, and 112.1 kg·ha^{-1}. The plots designated as Zero-N did not receive any additional fertilizer inputs post-establishment.

Each 32-m^2 (344.5-ft^2) nitrogen plot was subdivided into four 8-m^2 (86.1-ft^2) density subplots, and each density plot was subdivided into four 2-m^2 (21.5-ft^2) weed management options (WMO) plots. An untreated lane of about 0.3 m (0.98 ft) separated each WMO from its nearest neighbor (Fig. 1). Each density plot was separated by about 0.6 m (1.97 ft) from the nearest density plot, and the nitrogen plots were separated by at least 1 m (3.3 ft). The Pre-WMO subplots were treated annually with one preemergence application of napropamide. We applied the active ingredient (≈3 weeks after planting) at 3.36 kg·ha^{-1} (3.0 lb/acre) on 26 May 2000, and at 7.85 kg·ha^{-1} (7.0 lb/acre) on 13 Apr. 2001. Each year, overhead irrigation was applied for about 2 h to incorporate the herbicide into the soil.

The postemergence plots were treated with sethoxydim (Poast; BASF Corporation, Research Triangle Park, N.C.) by backpack sprayer on 26 June 2000 and 2 July 2001. Sethoxydim is a selective postemergence grass herbicide. A 1.5% solution of the herbicide plus 1% by volume crop oil concentrate was applied at a pressure of 206.8 kPa (30 psi). In addition, these plots were hand-weeded once each year (removing any living non-cranberry biomass) about 1 month after herbicide application. Time needed to remove the weeds from the Post-WMO plots was recorded.

In September of each year, all above- and belowground biomass was collected from within one 929-cm^2 (1-ft^2) quadrat randomly placed in each experimental unit. Conventional hand clippers were used to cut around the entire inner perimeter of the quadrat to permit collection of cranberry tissue or weeds that were passing through the quadrat. Samples were stored in brown paper bags at ambient temperatures until processed. During the processing, cranberry vines were sorted from all other plants, which were categorized as weeds. Aboveground cranberry biomass contained both runners and uprights (Eck, 1990). The reproductive status of the uprights was not evaluated as the primary goal in a new planting is to maximize vine coverage (vegetative growth) and minimize fruit production (DeMoranville et al., 2001). After sorting, samples were oven-dried for at least 36 h at 60 °C (140.0 °F) to quantify cranberry and weed dry biomass.

ECONOMIC ASSUMPTIONS. Economic estimates were calculated to permit comparisons of the treatment options in the study (Table 1). All estimates are computed in 2002 US dollars. Nitrogen material costs were based on two applications of the NPK formulation at \$1.54/kg (\$0.70/lb) and three applications of urea at \$0.64/kg

($0.29/lb). Labor costs for nitrogen application were assumed to be constant across all treatments and were not included in the calculations. The cost of the fertilizer treatment was then calculated based on nitrogen dose. Vine costs were based on a commercial rate for the cultivar, Stevens, of $1653/t ($1500/ton). Manual hand-weeding labor was estimated at $11/h (S. Knight, personal communication). In 2002, napropamide cost $5.24/kg ($2.38/lb) and sethoxydim cost $18.89/L ($71.50/gal) (M. Utley, personal communication). Labor costs to apply preemergence herbicide were estimated at $49.4/ha ($20/acre). A competent operator working on a regularly shaped, contiguous bog can cover about 4.9 $ha\cdot d^{-1}$ (12 acre/d) (B. Gilmore, personal communication). Postemergence herbicide product was applied at the rate of 15.6 $mL\cdot L^{-1}$ (2 fl oz/gal) with an estimated coverage potential of 74.3 m^2 (800 ft^2) with 3.79 L (1.0 gal) of herbicide solution. The estimated cost of treating 1 ha of grass-infested bog was therefore $150.31 ($60.83/acre).

Estimates for manual labors costs were made using time data collected when research technicians removed weeds from the Post-WMO (Sandler, 2004). These values were halved for the economic calculations and estimations for two reasons. First, it is very probable that full-time laborers would be much faster than the scientific personnel utilized in this study. Second, biomass was being collected for subsequent analysis. Although attempts were made to just hand-weed, extra time was likely expended to extract weeds in a fashion that would permit identification and accurate biomass evaluation. For these reasons, it was assumed that paid manual laborers would have worked twice as fast as the research personnel.

Results and Discussion

WEED COMMUNITY DESCRIPTION AND TREATMENT EFFECTS. The biological data used in the economic analysis were drawn from a larger study. More details are presented elsewhere (Sandler, 2004), but some general notes and descriptions are presented to provide background information. Annual vegetation surveys were conducted utilizing quadrat sampling, species identification, and visual estimates of percentage cover. Fifty-five different weed species were identified during the course of the study. The abundance and diversity of plant species varied with year, nitrogen rate, vine density, and WMO. The analyses were very detailed and are beyond the scope of the present paper.

A pest common to new plantings, nutsedge (*Cyperus dentatus*), occurred frequently but rarely exceeded 5% cover. Large crabgrass (*Digitaria sanguinalis*) also occurred frequently; its coverage often exceeded 10% in Year 1, but became much less abundant in Year 2. In contrast, hairgrass (*Muhlenbergia capallaris*) was rarely detected in Year 1, but often exceeded 10% cover in Year 2. In general, broadleaf and sedge species produced more biomass than grass and rush species. Narrow-leaved goldenrod (*Euthamia tenuifolia*), ragweed (*Ambrosia artemisiifolia*), pitchfork (*Bidens frondosa*), bent-grass (*Agrostis hyemalis*), panic-grass (*Panicum* spp.), st. john's wort (*Hypericum* spp.), and toadflax (*Linaria canadensis*) were also relatively abundant in one or both years. Most of these species are considered to be at least modestly problematic on commercial cranberry farms.

The effect of WMO on total weed biomass varied with nitrogen rate ($P < 0.001$); partitioning of the sum of squares indicated significance among WMO treatments within all nitrogen levels. Pre-WMO and Post-WMO had lower total weed biomass production than the Unt-WMO at all nitrogen rates. Nitrogen rate and vine density interacted to affect cranberry biomass production in Year 1 and Year 2 ($P = 0.05$ and $P < 0.001$, respectively). Partitioning of the sum of squares indicated significant effects of vine density at all nitrogen rates. The increase in cran-

Table 1. Estimated costs (in 2002 dollars) associated with establishing cranberry vines receiving various nitrogen rate, vine density, and preemergence or postemergence weed management options (Pre-WMO and Post-WMO, respectively) combinations in Year 1 and Year 2; L = labor, H = herbicide.

				Year 1				Year 2				Total costs	
Nitrogen rate	Vine density	Nitrogen costs	Vine costs	Pre-WMO		Post-WMO		Pre-WMO		Post-WMO			
				L	H	L	H	L	H	L	H	Pre	Post
($kg\cdot ha^{-1}$)[z]	($Mg\cdot ha^{-1}$)[y]	($/ha)[x]	($/ha)[w]	($/ha)				($/ha)				($/ha)	
0.0	0	0	0	50	176	1,323	150	50	411	5,317	150	687	6,940
	1.8	0	2,974	50	176	1,360	150	50	411	3,062	150	3,661	7,696
	3.6	0	5,947	50	176	917	150	50	411	2,124	150	6,634	9,288
	5.4	0	8,920	50	176	1,513	150	50	411	2,658	150	9,607	13,391
28.0	0	33	0	50	176	1,673	150	50	411	6,648	150	753	8,687
	1.8	33	2,974	50	176	2,063	150	50	411	8,122	150	3,727	13,525
	3.6	33	5,947	50	176	1,681	150	50	411	3,884	150	6,700	11,878
	5.4	33	8,920	50	176	2,926	150	50	411	3,482	150	9,673	15,694
56.0	0	66	0	50	176	2,498	150	50	411	8,773	150	819	11,703
	1.8	66	2,974	50	176	3,422	150	50	411	9,927	150	3,793	16,755
	3.6	66	5,947	50	176	1,857	150	50	411	5,754	150	6,766	13,990
	5.4	66	8,920	50	176	4,942	150	50	411	6,728	150	9,739	21,022
112.1	0	132	0	50	176	1,192	150	50	411	9,224	150	951	10,980
	1.8	132	2,974	50	176	978	150	50	411	5,515	150	3,925	10,031
	3.6	132	5,947	50	176	3,881	150	50	411	21,047	150	6,898	31,439
	5.4	132	8,920	50	176	2,192	150	50	411	11,615	150	9,871	23,291

[z] 1.0 $kg\cdot ha^{-1}$ = 0.89 lb/acre.
[y] 1.0 $Mg\cdot ha^{-1}$ = 0.45 ton/acre.
[x] $1/ha = $0.40/acre; nitrogen costs are the same for Year 1 and Year 2.
[w] Vine costs are expended in Year 1 only.

berry biomass production with increasing vine density was best described by nonlinear relationships at all nitrogen rates. Cranberry biomass production was also influenced by WMO. Pre-WMO plots produced more cranberry biomass than Unt-WMO (Kramer-adjusted Tukey's honestly significantly different test, $P = 0.05$). Post-WMO plots tended toward higher amounts of biomass than Unt-WMO, but were statistically similar to both Pre-WMO and Unt-WMO plots.

Weeds vary in their ability to colonize, reduce cranberry yield, and susceptibility to control (Else et al., 1995). For the purposes of this study, we assumed that most growers would be trying to manage a community of weeds, and that either preemergence or postemergence weed management would provide some degree of control for the complex of weed species present. The variation in competitive ability among weeds was not factored into the economic analysis. The main goal in establishing a new planting is to encourage and maximize the colonization of cranberry vines to all available open space. In the first year or two of establishment, it would be our contention that the threshold for weed tolerance would be relatively equalized across species. All weeds are competing with cranberry for water, nutrients, light, and space. With this in mind, many of weed species in the field study would be considered relatively easy to control with current management tools. Species considered difficult to control as well as detrimental to cranberry growth, such as bristly dewberry (*Rubus hispidus*), silverleaf sawbrier (*Smilax glauca*), and poison ivy (*Toxicodendron radicans*), were not identified during the first 2 years of the new planting.

Though the specific composition of the weed community would likely vary from site to site, it is not unreasonable to assume that the weed pressure present at the experimental site would be similar to weed infestation potential present at other new planting sites. Since the study was established in a commercial setting with conventional plant material and planting equipment, we believe that the experimental site was subjected to similar conditions that would permit the development of (potential) weed communities typical of new commercial plantings. This observation is based on the personal experiences of the authors. An industry-wide survey of weed communities present on new plantings has not been conducted, and this could be an area of future research. Nitrogen rate, vine density, and WMO interacted to affect end-of-season weed biomass (Sandler, 2004). Thus, the weed biomass specific for each respective treatment combination was utilized to develop the economic analysis.

Certainly, other weed management strategies could have been selected for incorporation into the study. Napropamide is the only preemergence herbicide recommended for use on new plantings and was the primary chemical treatment. Other preemergence herbicides registered for cranberry production [e.g., dichlobenil (Casoron; PBI Gordon Corporation, Kansas City, Mo.), norflurazon (Evital; Syngenta Crop Protection, Inc., Greensboro, N.C.)] cause moderate to severe vine phytotoxicity to newly planted vines. When designing the study, we also wanted to examine the potential of obtaining adequate weed control with lowered chemical inputs. The use of hand-labor (nonchemical weed management) was the primary treatment consideration for the Post-WMO. However, since grasses are common on newly planted cranberry beds in Massachusetts, the selective grass herbicide, sethoxydim, was also included in the Post-WMO. While the use of glyphosate (Roundup; Monsanto Agricultural Company, St. Louis, Mo.) was considered, it has a higher potential for causing vine injury and was not included in the study. Growers could opt to use glyphosate as part of their new planting weed management, and might obtain results different than those discussed in this study.

ECONOMIC ANALYSIS. The effect of WMO on total cost, cost to produce

Table 2. Production of cranberry biomass in plots treated with preemergence or postemergence weed management options (Pre-WMO and Post-WMO, respectively) at the end of 2 years, and cost to produce 1 kg (2.2 lb) of cranberry biomass. Values are the mean ± SE of four replications; NA = not applicable.

Nitrogen rate ($kg \cdot ha^{-1}$)[z]	Vine density ($Mg \cdot ha^{-1}$)[y]	Cranberry biomass ($g \cdot m^{-2}$)[x]		Cost to produce 1 kg of cranberry biomass ($)[w]	
		Pre-WMO	Post-WMO	Pre-WMO	Post-WMO
0.0	0	0 ± 0	0 ± 0	NA	NA
	1.8	185 ± 30	201 ± 22	2.15 ± 0.37	3.96 ± 0.39
	3.6	232 ± 49	268 ± 20	3.64 ± 1.24	3.52 ± 0.26
	5.4	324 ± 27	334 ± 36	3.02 ± 0.22	4.16 ± 0.44
28.0	0	0 ± 0	0 ± 0	NA	NA
	1.8	368 ± 60	331 ± 67	1.10 ± 0.18	4.60 ± 0.89
	3.6	672 ± 60	494 ± 52	1.01 ± 0.10	2.49 ± 0.25
	5.4	625 ± 79	632 ± 60	1.62 ± 0.21	2.56 ± 0.24
56.0	0	0 ± 0	0 ± 0	NA	NA
	1.8	752 ± 116	661 ± 143	0.54 ± 0.09	2.83 ± 0.46
	3.6	864 ± 47	805 ± 146	0.79 ± 0.04	1.97 ± 0.44
	5.4	820 ± 157	758 ± 98	1.42 ± 0.41	2.90 ± 0.33
112.1	0	0 ± 0	0 ± 0	NA	NA
	1.8	699 ± 105	583 ± 15	0.60 ± 0.08	1.73 ± 0.04
	3.6	1004 ± 95	918 ± 115	0.71 ± 0.06	3.64 ± 0.58
	5.4	1020 ± 92	961 ± 48	0.99 ± 0.09	2.44 ± 0.12

[z] 1.0 $kg \cdot ha^{-1}$ = 0.89 lb/acre.

[y] 1.0 $Mg \cdot ha^{-1}$ = 0.45 ton/acre.

[x] 1 $g \cdot m^{-2}$ = 0.0033 oz/ft^2.

[w] $1.00/kg = $0.45/lb.

cranberry biomass, % weed control, and cost to achieve weed control varied with nitrogen rate and vine density ($P \leq 0.004$). Within each nitrogen rate, all pairwise comparisons of total cost (Table 1) were different from one another ($P < 0.001$). Within each nitrogen rate (except Zero-N), density and WMO interacted to affect the cost to produce cranberry biomass (Table 2). Within these three nitrogen rates (and excluding Zero-D), the cost to produce cranberry biomass was less expensive for Pre-WMO than its corresponding Post-WMO. For Zero-N, cranberry biomass increased linearly as vine density increased, and Pre-WMO and Post-WMO had more biomass than Unt-WMO. Within each nitrogen rate, percentage weed reduction was similar for Pre-WMO and Post-WMO combinations except for Med-N/Zero-D (Table 3). Weed control with Pre-WMO cost less to achieve than Post-WMO at all densities at low and medium nitrogen rates (except Low-N/Med-D).

Overall, Pre-WMO total costs were lower than Post-WMO. Pre-WMO costs for herbicide and labor were constant across all densities; thus cost variations in Year 1 were attributable to vine and fertilizer costs (Table 1). For Post-WMO combinations, herbicide costs were constant; labor costs determined the price differences seen in Post-WMO. Labor costs ranged from $917/ha to $4942/ha ($371/acre to $2000/acre) in Year 1.

In Year 2, the cost differential between Pre-WMO and Post-WMO became apparent (Table 1). The lowest labor costs associated with any Post-WMO [$2124/ha ($860/acre) in Zero-N/Med-D] were more than four times greater than all costs associated with Pre-WMO [$461/ha ($187/acre)]. Relative to each nitrogen/density combination, Post-WMO plots were much more expensive to maintain in Year 2 compared to Year 1. The largest increase in labor (hand-weeding) costs was in High-N/Zero-D, which was 674% higher in Year 2 compared to Year 1. The costs associated with hand-weeding the other High-N plots rose about 450% from Year 1 to Year 2. The smallest increases in the cost of postemergence control were in the Low-N/High-D and Med-N/High-D plots, where low to moderate labor costs increased by 19% [$2926/ha to $3482/ha ($1184/acre to $1409/acre)] and 36% [$4942/ha to $6728/ha ($2000/acre to $2723/acre)], respectively.

When the costs of the first 2 years were combined, Pre-WMO plots had lower total costs than the Post-WMO (Table 1). Overall, Post-WMO plots were about twice as expensive to manage as Pre-WMO plots (values ranged from 40% to 356% increases for vine-containing plots). The Med-N/Low-D (342% increase), High-N/Med-D (356%), and Low-N/Low-D plots (263%) were at least three times more expensive to manage with postemergence options compared to preemergence options. The smallest increase in total costs between Pre-WMO and Post-WMO was with the Zero-N/Med-D and Zero-N/High-D combinations (40% increases). Overall, the Zero-N/Low-D [$7696/ha ($3115/acre)] and Zero-N/Med-D plots [$9288/ha ($3759/acre)] were the least expensive vine-containing plots to manage postemergence.

The amount of money needed to produce 1 kg (2.2 lb) of cranberry biomass was calculated (Table 2). The total cost associated with each treatment combination was divided by the total cranberry biomass produced by the end of Year 2 in each Pre-WMO and Post-WMO plot. Cranberry establishment was judged to be successful by both qualitative visual assessment (% cover) and quantitative biomass production, without growth becoming overly vegetative (Sandler, 2004). Excessive vegetative growth (Davenport and Vorsa, 1999; Hart et al., 1990) is undesirable as the ultimate commercial goal is to produce fruit. For the purposes of this study, combinations that produced more than 808 $g \cdot m^{-2}$ (2.64 oz/ft^2) were considered overly vegetative. Cranberry biomass production in the range of 657 to 808 $g \cdot m^{-2}$

Table 3. Weed biomass production in plots treated with preemergence, postemergence weed management options or untreated (Pre-WMO, Post-WMO, and Unt-WMO, respectively) at the end of 2 years, percent weed reduction for each nitrogen rate-vine density combination, and costs to reduce weed biomass by 1%. Values are the mean ± SE of four replicates.

Nitrogen rate ($kg \cdot ha^{-1}$)[z]	Vine density ($Mg \cdot ha^{-1}$)[y]	Weed biomass ($g \cdot m^{-2}$)[x]			Weed reduction (%)		Cost to reduce weed biomass by 1% ($)	
		Pre-WMO	Post-WMO	Unt-WMO	Pre	Post	Pre	Post
0.0	0	37 ± 9	48 ± 22	167 ± 44	76 ± 5	70 ± 13	9 ± 1	116 ± 31
	1.8	15 ± 3	10 ± 5	48 ± 27	51 ± 16	77 ± 8	101 ± 31	105 ± 14
	3.6	8.0 ± 2	4 ± 1	117 ± 71	78 ± 12	91 ± 6	94 ± 19	104 ± 8
	5.4	21 ± 8	7 ± 3	102 ± 24	73 ± 14	92 ± 4	162 ± 52	147 ± 6
28.0	0	122 ± 52	31 ± 9	425 ± 109	70 ± 13	91 ± 3	13 ± 4	96 ± 3
	1.8	91 ± 46	42 ± 10	441 ± 135	77 ± 8	92 ± 2	50 ± 5	147 ± 3
	3.6	72 ± 29	17 ± 10	218 ± 67	70 ± 13	94 ± 2	111 ± 28	127 ± 2
	5.4	39 ± 24	7 ± 3	351 ± 99	89 ± 6	98 ± 1	110 ± 8	161 ± 1
56.0	0	458 ± 59	72 ± 22	564 ± 56	19 ± 8	88 ± 3	28 ± 11	134 ± 5
	1.8	65 ± 20	77 ± 38	426 ± 218	85 ± 5	80 ± 6	45 ± 2	213 ± 18
	3.6	55 ± 22	30 ± 22	422 ± 57	87 ± 6	90 ± 8	81 ± 6	161 ± 19
	5.4	88 ± 58	49 ± 38	470 ± 121	76 ± 12	88 ± 8	141 ± 24	245 ± 24
112.1	0	396 ± 165	45 ± 15	1464 ± 321	76 ± 5	96 ± 2	13 ± 1	114 ± 3
	1.8	267 ± 118	64 ± 20	641 ± 133	64 ± 10	89 ± 5	66 ± 12	114 ± 7
	3.6	226 ± 151	58 ± 25	579 ± 148	61 ± 19	82 ± 13	165 ± 53	426 ± 91
	5.4	140 ± 57	30 ± 12	417 ± 43	68 ± 13	92 ± 3	173 ± 50	253 ± 8

[z] 1.0 $kg \cdot ha^{-1}$ = 0.89 lb/acre.

[y] 1.0 $Mg \cdot ha^{-1}$ = 0.45 ton/acre.

[x] 1 $g \cdot m^{-2}$ = 0.0033 oz/ft^2.

(2.15 to 2.64 oz/ft^2) was considered sufficient. Thus, solely in terms of sufficient (but not excessive) cranberry biomass production and good weed control, five three-way combinations were qualitatively identified (Table 2) as effective treatments: Med-N/Med-D/Post-WMO [805 g·m^{-2} (2.63 oz/ft^2), 90% weed reduction], Med-N/High-D/Post-WMO [758 g·m^{-2} (2.48 oz/ft^2), 88% reduction], Med-N/Low-D/Pre-WMO [752 g·m^{-2} (2.46 oz/ft^2), 85% reduction], Low-N/Med-D/Pre-WMO [672 g·m^{-2} (2.20 oz/ft^2), 70% reduction], and Med-N/Low-D/Post-WMO [661 g·m^{-2} (2.16 oz/ft^2), 80% reduction].

The most cost-effective treatment overall, in terms of efficiently maximizing cranberry biomass production while also achieving good weed control, was the Med-N/Low-D/Pre-WMO treatment (752 g·m^{-2}, 85% weed reduction). One kg of cranberry biomass was produced for each \$0.54 (\$0.24/lb) spent (Table 2). High-N/Low-D/Pre-WMO and High-N/Med-D/Pre-WMO were other combinations that were very cost-efficient in terms of vine production, with costs of \$0.60 and \$0.71 per kg (\$0.27 and \$0.32 per lb) cranberry biomass, respectively. However, these combinations had poorer weed control (about 60% weed biomass reduction) than most other treatment combinations (Table 3). The Low-N/Med-D/Pre-WMO produced sufficient cranberry biomass and had good weed control (produced 672 g·m^{-2}, 70% weed reduction). However, costs were nearly twice as high [\$1.01/kg (\$0.46/lb)] to produce cranberry biomass with this treatment combination compared to Med-N/Low-D/Pre-WMO, and weed control was poorer. The most cost-effective Post-WMO, that produced sufficient cranberry biomass with good weed control, was the Med-N/Med-D combination, with costs of \$1.97/kg (\$0.89/lb) cranberry biomass produced.

Unquestionably, examination of gross cranberry biomass production or weed control alone is not necessarily the only way to predict commercial success of a young planting. The criteria for successful initial establishment are quick and thorough coverage of the ground surface by runners (DeMoranville et al., 2001). However, fruit production is most influenced by the number of flowering uprights and percent fruit set (Eaton and MacPherson, 1978). Once adequate ground colonization is attained, the grower must practice good horticultural techniques (e.g., frost protection, pollination, sanding) to promote the production of uprights and fruit.

The costs associated with achieving high percentages of weed reduction were variable (Table 3). Costs to reduce weed biomass was calculated by determining the percentage weed reduction for Pre-WMO and Post-WMO compared to the untreated, and dividing the total cost of that treatment combination by the % weed reduction. Post-WMO combinations were successful in reducing weed biomass, but at much higher costs than the Pre-WMO. Considering three-way combinations that contained cranberry vines, costs ranged from \$45 to \$426 to reduce weed biomass by 1%. Cost of obtaining the best weed control (for a vine-containing combination) was fairly expensive; the Low-N/High-D/Post-WMO (98% control) treatment needed \$161 for each percent reduction in weed biomass.

Even though the Med-N/Low-D/Pre-WMO (\$0.54 to produce 1 kg cranberry biomass) had less weed control (85% reduction) than many other three-way combinations, this treatment gave very cost-effective weed control (\$45 for each percentage reduction) (Table 3). Notably, Low-N/Med-D/Pre-WMO, one of the most cost-efficient combinations at producing cranberry biomass (\$1.01/kg), ranked among the lowest in terms of overall weed control (70% reduction), and was more than twice as expensive (\$111 for each percentage weed reduction) as the Med-N/Low-D/Pre-WMO in terms of applying the WMO. Med-N/Med-D/Pre-WMO was fairly cost-efficient at minimizing weed biomass (\$81 for each percentage weed reduction), had good weed control (87% biomass reduction), and ranked among the most cost-effective combinations in producing 1 kg of cranberry biomass [\$0.79/kg (\$0.36/lb)].

The best three-way combinations in terms of overall weed reduction were not necessarily the most cost-efficient at reducing weed biomass. Hand-weeding, an option that could be chosen by growers seeking to reduce chemical inputs, is very effective for weed control but is typically associated with high labor costs. For example, Low-N/High-D/Post-WMO and High-N/High-D/Post-WMO reduced weed biomass by 98% and 92% compared to the untreated, respectively, but at a cost of \$161 and \$253 for each percentage of biomass reduction, respectively. The most cost-efficient combinations for weed control (of those containing cranberry vines) were the Low-D/Pre-WMO at all nitrogen rates (less than \$66); however, the High-N gave poor weed control for dollars spent (64% reduction). The Zero-N/Med-D/Pre-WMO and Med-N/Med-D/Pre-WMO combinations were also reasonably effective and cost-efficient at reducing weed biomass, costing \$94 (78% reduction) and \$81 (87% reduction) for each percentage reduction, respectively.

No yield data were collected in 2000 as the vines were newly planted. Unfortunately, no yield data were collected from the study in 2001 due to an infestation of insecticide-resistant cranberry weevils (*Anthonomus musculus*) at the field site. 'Stevens' is a high-yielding, vigorous hybrid and is gaining in popularity in the Massachusetts industry, especially for use in new plantings. Though seldom prolific enough for measurable market returns, it was reasonable to expect some initial fruit production from this cultivar in its second year. Unfortunately, the weevil infestation was severe and no viable insect management options were available in 2001. In some locations of the production area, zero fruit were produced. Plots will be maintained for at least 2 more years (through the 2003 field season) to collect additional yield data. Any relevant findings will be presented in future publications.

The focus of this research was to compare establishment costs associated with various combinations of nitrogen rates, vine densities, and weed management choices. The primary interest was to determine which combination(s), from a biological and economic perspective, could produce substantial cranberry coverage while minimizing weed infestation. At the onset of the project, it was not clear how many years would be needed to achieve adequate coverage with any particular combination, and whether or not yield income would be significant during the establishment period. After 2 years, several combinations produced vine coverage and weed management that would be deemed commercially successful. However, since most cultivars do not produce a substantial, marketable harvest until the third (or later) year, we believe that yield income would not substantially offset labor or other costs for the purposes of vine establishment. Obviously, yield income is an important factor in any economic analysis projecting the long-term profit or loss associated with establishing and farming a commercial cranberry bed.

Based on our present data, we cannot evaluate the long-term income that would be associated with our tested treatment combinations. However, cranberry yield is associated with the number of fruiting uprights and percentage fruit set (Eaton et al., 1983). Characterized by dense upright production with minimal runner (vegetative) growth, treatment combinations that produced sufficient cranberry biomass along with good weed control (our criteria for selecting successful treatments), would be expected to produce reasonable yield.

Conclusions

Based solely on the criterion of sufficient (but not excessive) cranberry biomass production, five three-way combinations gave promising forecasts for cranberry establishment: Low-N/Med-D/Pre-WMO, Med-N/Low-D/Pre-WMO, Med-N/Low-D/Post-WMO, Med-N/Med-D/Post-WMO, and Med-N/High-D/Post-WMO. These treatments had good vine coverage (without excessive vine growth) and reasonably good weed control. Of this group, Low-N/Med-D/Pre-WMO and Med-N/Low-D/Pre-WMO were very cost-efficient for producing cranberry biomass. These two treatments, as well as Low-N/Low-D/Pre-WMO, Med-N/Med-D/Pre-WMO, High-N/Low-D/Pre-WMO, High-N/Med-D/Pre-WMO, and High-N/High-D/Pre-WMO, could produce 1 kg of cranberry biomass for about $1.00 ($0.45/lb) or less. In spite of the vine biomass cost-efficiency, all of the High-N/Pre-WMO combinations had poor weed control and/or produced overly vegetative growth, and these combinations would be considered commercially undesirable.

While other combinations could provide positive results for growers depending on their marketing and farm management goals, the Low-D/Pre-WMO combinations were generally very cost-efficient for producing cranberry biomass and reducing weed biomass. Although the Zero-N/Low-D and the Low-N/Low-D were reasonably efficient at producing cranberry biomass, these treatments attained less than 60% coverage of the bog surface by the end of Year 2 (Sandler, 2004). The Med-N/Low-D and High-N/Low-D combinations had between 90% to 100% coverage by the end of 2 years, but varied in weed control (85% and 64% control, respectively). Synthesizing the success rates in both biological and economic terms, Med-N/Low-D/Pre-WMO ($0.54 per kg cranberry, $45 for each percentage weed reduction, and 85% weed control) was the production scheme that most cost-efficiently maximized optimal cranberry biomass production and minimized weed biomass production.

Three out of the five combinations identified as yielding sufficient cranberry biomass production and weed control were Post-WMO combinations. Most growers would not choose to manage weed populations by hand-weeding alone, unless they were using organic management practices. The Post-WMO combinations gave at least 80% weed control, but at a cost much higher than associated with Pre-WMO. However, given the additional monetary incentives associated with organic or niche market fruit, several of the Post-WMO combinations might be acceptable for establishing new plantings under organic management programs.

Labor costs disproportionately dominated the total costs associated with the Post-WMO combinations. Our projection of labor costs was based on the time needed to hand-weed plots, a task which was performed by research technicians who were collecting the weeds for identification and processing. We assumed paid laborers would be twice as fast as the research technicians. This may be a conservative assumption as people vary in their ability to hand-weed. Thus, depending on the proficiency of laborers employed, actual costs associated with Post-WMO combinations could be lower than those reported here.

Recommendations for Growers

The data suggest that the most cost-effective production scheme for establishing a new bog is to plant vines at a low density, use moderate rates of nitrogen, and apply a yearly application of napropamide for weed control (Med-N/Low-D/Pre-WMO). This combination efficiently produced optimal vine coverage, reduced weed biomass by 85% compared to untreated plots, and gave the best weed control per dollar spent. Though the cost of producing 1 kg of cranberry biomass nearly doubles ($1.01/kg), the reduced nitrogen inputs of the Low-N/Med-D/Pre-WMO combination might be a viable option in areas of water quality concern. Weed control was moderate (70% reduction) with this option, and cost $111 for each percentage weed reduction. In medium-density plantings that received moderate amounts of nitrogen, substituting postemergence weed management for the preemergence treatment doubled the cost to achieve similar weed control ($81 to $161 for each percentage reduction).

Although the Med-N/High-D/Post-WMO combination was successful in terms of vine coverage (90% to 100% by the end of 2 years), the expense of producing the vines [$2.90 to produce 1 kg ($1.32/lb)] and weed control costs ($245 for each percentage weed reduction) diminishes the economic practicality of this treatment. Some combinations were as cost-efficient in producing cranberry biomass and applying weed management as the Med-N/Low-D/Pre-WMO (e.g., High-N/Low-D/Pre-WMO). This treatment, however, had poorer weed control (64% weed reduction).

Post-WMO could be considered in situations where growers prefer a nonchemical alternative. Costs may be slightly higher than documented in this study since a selective postemergence herbicide was used to control a portion of the grass population. Extra labor costs would be incurred to remove any additional biomass produced by this plant group. Most growers who are considering organic production should anticipate higher operational costs than conventional cranberry growing (Sandler, 2001). Though typically minor during the first 2 years of establishment, additional costs for insect and disease management also need to be factored into any cost analysis.

The cost of producing 1 kg of cranberry in Med-N/Low-D/Post-WMO and the Med-N/Med-D/Post-WMO combinations [$2.83/kg and $1.97/

kg ($1.28/lb and $0.89/lb), respectively) would replace the successful Pre-WMO (costs less than $0.79/kg). In addition, the expense required to obtain weed control with these two Post-WMO combinations would increase ($213 for each percentage reduction with 80% weed control, and $161 for each percentage reduction with 90% weed control, respectively) compared to the Pre-WMO (costs less than $81 for each percentage reduction with 85% weed control). Even with these slightly higher expenditures needed to produce cranberry biomass and control weeds with Post-WMO, the additional revenues from organic or other niche-market products may, under the right circumstances, offset the higher initial establishment costs.

Prices for organic fruit can vary widely from year to year and region to region. Fluctuations in prices for developing markets, such as organic cranberry fruit (fresh and processed), must be evaluated when making production decisions. However, in the current situation, the potential retail value of processed organic cranberry fruit exceeds the payback from conventional fruit by 2- to 4-fold (J. Carlson, personal communication). Growers should bear in mind that data from this study focused only on the initial establishment period for a cranberry bed, and did not incorporate offsets from fruit production. Growers must carefully evaluate whether the labor costs involved in the initial (nonchemical) establishment process outweigh the costs involved with establishing a planting with chemicals, followed by a transition to organic production. In the final analysis, many factors other than weed control and vine coverage will affect whether or not nonchemical production of cranberry fruit will be profitable.

Weed scientists have acknowledged that the diversity of weed communities will determine the nature of weed management options and changes in weed diversity may present potential weed management problems (Derksen et al., 1995). Integrated weed management strategies can influence the composition of the weed flora in agricultural settings (Andersson and Milberg, 1998). In the current study, nitrogen rate, vine density, and WMO interacted to impact the composition, occurrence and coverage of weed species and cranberry in newly established plantings. Several treatment combinations offer reasonable formulas for attaining substantial cranberry vine coverage of the bare surface while minimizing weed establishment. Other farms will likely have different plant communities than the one described in this study. Thus, scouting should be employed to identify the various plant groups or species prior to selecting a weed management plan at a given site.

This study has shown that a small array of three-way combinations of nitrogen rate, vine density, and weed management can lead to the successful establishment of a new cranberry planting. This study evaluated the vigorous hybrid cultivar, Stevens; it is reasonable to expect that other cultivars may vary somewhat in response to vine density and nitrogen rate schemes from those reported here. Growers may need to use higher initial densities with less vigorous cultivars such as Early Black and Howes. New, vigorous hybrids are anticipated for release into the industry over the next few years (J. DeVerna, personal communication). Data from this study should provide a reasonable guideline as it is anticipated that many growers will opt to re-plant with either 'Stevens' or one of the new cultivars. For most growers, the use of preemergence and postemergence weed control options are not mutually exclusive, and an integration of management tactics will most likely be used. The choice of a particular nitrogen rate-vine density-weed management combination will depend on the available local resources (e.g., vine cuttings), monetary assets, and desired farm strategies (i.e., organic vs. conventional).

Literature cited

Andersson, T.N. and P. Milberg. 1998. Weed flora and the relative importance of site, crop, crop rotation, and nitrogen. Weed Sci. 46:30–38.

Davenport, J.R. and N. Vorsa. 1999. Cranberry fruiting and vegetative response to nitrogen fertilizer in cranberry. J. Amer. Soc. Hort. Sci. 124:90–93.

DeMoranville, C.J., H.A. Sandler, and T. Bicki. 1996. Best management practices guide for cranberry production in Massachusetts. Univ. Mass. Cranberry Sta. Ext. Publ., East Wareham.

DeMoranville, C.J., H.A. Sandler, and F.L. Caruso. 2001. Planting new cranberry beds. Univ. Mass. Cranberry Sta. Ext. Publ., East Wareham.

Derksen, D.A., A.G. Thomas, G.P. Lafond, H.A. Loeppky, and C.J. Swanton. 1995. Impact of post-emergence herbicides on weed community diversity with conservation-tillage systems. Weed Res. 35: 311–320.

Eaton, G.W. and E.A. MacPherson. 1978. Morphological components of yield in cranberry. Hort. Res. 17:73–82.

Eaton, G.W., A.Y. Shawa, and P.A. Bowen. 1983. Productivity of individual cranberry uprights in Washington and British Columbia. Sci. Hort. 20:179–184.

Eck, P. 1990. The American cranberry. Rutgers Univ. Press, New Brunswick, N.J. p. 43-55.

Else, M.J., H.A. Sandler, and S. Schluter. 1995. Weed mapping as a component of integrated pest management in cranberry production. HortTechnology 5: 302–305.

Greidanus, T., L.A. Peterson, L.E. Schrader, and M.N. Dana. 1972. Essentiality of ammonium for cranberry nutrition. J. Amer. Soc. Hort. Sci. 97:272–277.

Hart, J.M., A. Poole, K.L. Wilder, and B.C. Strik. 1990. Nitrogen rate and timing affect on cranberry yield and yield components. HortScience 25:1148.

Rosen, C.J., D.L. Allan, and J.L. Luby. 1990. Nitrogen form and solution pH influence growth and nutrition of two *Vaccinium* clones. J. Amer. Soc. Hort. Sci. 115:83–89.

Sandler, H.A., Ed. 2001. Third organic cranberry growing conference. Univ. Mass. Cranberry Sta. Ext. Publ., East Wareham.

Sandler, H.A. 2004. Factors influencing the colonization and establishment of plant species on cranberry bogs. PhD diss. Univ. Mass., Amherst.

Strik, B.C., Ed. 2002. Cranberry production in the Pacific Northwest. PNW 247. Ore. St. Univ. Ext. Serv., Ore. St. Univ., Corvallis.