Weed Technology

www.cambridge.org/wet

Exploring the influence of weeds on cranberry yield and quality

Jed Colquhoun[1], Thierry Besançon[2], Katherine Ghantous[3] and Hilary Sandler[4]

[1]Professor, Department of Horticulture, University of Wisconsin-Madison, Madison, WI, USA; [2]Associate Professor and Extension Specialist, Rutgers University Philip E. Marucci Center for Blueberry and Cranberry Research, Chatsworth, NJ, USA; [3]Research Associate, University of Massachusetts Cranberry Station, East Wareham, MA, USA and [4]Extension Professor, University of Massachusetts Cranberry Station, East Wareham, MA, USA

Research Article

Cite this article: Colquhoun J, Besançon T, Ghantous K, Sandler H (2022) Exploring the influence of weeds on cranberry yield and quality. Weed Technol. **36**: 390–396. doi: 10.1017/wet.2022.28

Received: 17 December 2021
Revised: 16 February 2022
Accepted: 21 March 2022
First published online: 19 April 2022

Associate Editor:
Peter J. Dittmar, University of Florida

Nomenclature:
Bristly dewberry; *Rubus hispidus* L.; Carolina redroot; *Lachnanthes caroliana* (Lam.) Dandy; polytrichum moss; *Polytrichum commune* Hedw.; earth loosestrife; *Lysimachia terrestris* (L.) Britton; Sterns & Poggenb.; cranberry; *Vaccinium macrocarpon* Ait.

Keywords:
weed interference; weed competition; crop quality; thresholds

Author for correspondence:
Jed Colquhoun, Department of Horticulture, 1575 Linden Drive, University of Wisconsin-Madison, Madison, WI 53706.
Email: colquhoun@wisc.edu

Abstract

The influence of weeds on cranberry yield and quality is not well known and cannot be extrapolated from other cropping systems given the unique nature of both cranberry production and the weed species spectrum. The work presented here addresses this need with four common weed species across multiple production seasons and systems in Wisconsin, Massachusetts, and New Jersey: Carolina redroot, earth loosestrife, bristly dewberry, and polytrichum moss. The objectives were to use these representative species to quantify the impact of weed density, groundcover, and biomass on several cranberry yield components and related interactions with other cranberry pests, and to determine whether these relationships were consistent enough across seasons to be reliably used in weed management decision-making. The relationships between Carolina redroot and bristly dewberry growth measures and marketable cranberry yield were highly significant ($P \leq 0.001$ in 12 of 13 regressions) and consistent across growing seasons, but not significant for similar regressions with earth loosestrife. In particular, the strong relationship between Carolina redroot and bristly dewberry visual groundcover observations and cranberry yield suggests a simple way for growers and crop scouts to reliably estimate yield loss. The relationship between polytrichum moss biomass and cranberry yield was also significant in both years, but not consistent between years. Weed competition also affected cranberry quality, in that Carolina redroot density was strongly related to the percentage of insect-damaged fruit and bristly dewberry growth reduced cranberry color development. On a practical level, this information can be used to educate growers, consultants, agrichemical registrants, and regulators about the impacts of weeds on cranberry yield and quality, and to economically prioritize management efforts based on the weed species and extent of infestation.

Introduction

Cranberry is a perennial crop grown primarily in North America. The United States and Canada dominate production with 98,000 and 50,000 ha, respectively, in 2017 (Sandler 2018). In South America, approximately 4,200 ha were in production in Chile in the same year, along with minor hectarage distributed across Eastern Europe and the Netherlands. In the United States, more than half the hectarage is in Wisconsin (8,421 ha), followed by Massachusetts (5,292 ha) and New Jersey (1,215 ha). The overall farmgate crop value for the U.S. crop was \$291 million in 2020 (USDA-NASS 2021).

Cranberry beds remain in continuous production for many seasons given that berry yield does not tend to decline over the years (as with other perennial crops) coupled with the high cost to renovate a planting (the process by which cranberry beds are modified and replanted). In 2009, it was estimated that the median cost to renovate Massachusetts cranberry farms was \$81,000 ha^{-1} (Gordon 2009). Moreover, newly renovated cranberry plantings do not produce a profitable berry yield until the third or fourth season, when the plants are established and stolons (i.e., runners) have colonized the bed to form continuous canopy cover. The long-term nature of cranberry plantings and dense vine ground cover limit the ability to use rotation or cultivation methods for weed management. Thus, weed control is almost exclusively limited to herbicide application. Common residual herbicides include dichlobenil, napropamide, or sulfentrazone applied prior to weed growth and when cranberry vines are dormant. Mesotrione, quinclorac, and graminicides are applied postemergence during active cranberry growth. Additionally, glyphosate, clopyralid, and 2,4-D can be used in selected applications, such as with a wick wiper, to control late-season weeds that escape previous applications (Guedot et al. 2021).

The weed spectrum in cranberry is unique given the crop's perennial nature and distinct production habitat. The cultivated American cranberry is native to North America and requires acidic, moist soils in cool climates (Hoekstra et al. 2020). Most weeds commonly found in

© The Author(s), 2022. Published by Cambridge University Press on behalf of the Weed Science Society of America.

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press

cranberry are perennials, and many are native wetland species (Colquhoun et al. 2009; Sandler et al. 2015). The influence of these weeds on cranberry yield and quality is not well known and cannot be extrapolated from other cropping systems given the unique nature of both cranberry production and the weed species spectrum. In Massachusetts, a weed species prioritization system was developed in 1995 that uses expert and grower input across three categories: rate of spread, potential to cause crop loss, and control difficulty (Else et al. 1995). A Canadian group of researchers published a revised priority rating system that attributed point scores to four criteria: impact, biological form or type, invasive or reproductive capacity, and adaptation to cranberry habitat (Neron et al. 2013). These systems are used to generate priority ratings ranging from low to very high that growers can use as a general guide for directing management efforts.

To the best of our knowledge, despite more than 200 yr of commercial production in the United States (Sandler 2018), reports of direct quantification of weed impact on cranberry yield and quality is limited to a single paper by Patten and Wang (1994), in which three perennial weed species were investigated: Pacific silverleaf [*Argentina egedii* (Wormsk.) Rydb. ssp. *Egedii*], birdsfoot trefoil (*Lotus corniculatus* L.), and Douglas aster [*Symphyotrichum subspicatum* (Nees) G.L. Nesom var. *subspicatum*]. Regression analysis was used to explore the relationship between weed canopy density and cranberry yield and quality. The authors reported that weed density reduced cranberry yield in a linear relationship and that berry yield was more sensitive to weed interference than berry quality. They further hypothesized that light was the most limiting factor in the competitive relationship and suggested additional research to investigate the long-term impact of established weed populations on cranberry yield components. Although qualitative data support the contention of yield loss due to weed competition including an expert input system (via a survey of weed scientists and outreach specialists) to estimate 25% yield loss across species (Swanton et al. 1993), quantitative data on weed impacts on cranberry yield are lacking.

The work presented here addresses the needs described above with four common weed species across multiple production seasons and systems in Wisconsin, Massachusetts, and New Jersey. Weed species were chosen that represent diverse phenology and growth habits. Carolina redroot is a perennial herbaceous plant with a fibrous root system and is native to the southeastern United States. It has grass-like leaves that extend to about 0.5 m tall and produces cream-colored flowers in early summer that are attractive to pollinators. It frequently colonizes New Jersey cranberry beds, where it often forms monoculture patches (Besançon et al. 2019). Earth loosestrife is another perennial herbaceous species of wetland areas in North America. It is propagated primarily by producing long and deep rhizomes throughout the growing season, and secondarily by bulblets located in the leaf axils in fall. Bristly dewberry is a perennial subshrub native to the eastern half of North America. In spring, emerging from extensive perennial crowns and roots it produces vines that spread across the top of the cranberry canopy. Polytrichum moss, also commonly known as haircap moss, is found in moist habitats across North America, Eurasia, and Australia. It is a perennial spore-producing plant that forms long-living, dense, and deep mats in moist cranberry beds (Sandler et al. 2015; USDA-NRCS 2021).

The primary objective was to use these representative species to quantify the impact of weed density, groundcover, and biomass on several cranberry yield components and related interactions with other cranberry pests. The long-term goal is to build a “library” of objective weed impact information that growers and consultants could use to make weed management decisions such as balancing control costs with the weed species’ economic impact on production. Also, the interaction of weeds with other cranberry pests, such as insects and plant pathogens, can be documented relative to berry yield and quality and in a way that is useful in making integrated pest management decisions if this relationship is consistent over production years.

Materials and Methods

Studies were conducted in 2018 through 2020 at the P.E. Marucci Center for Blueberry and Cranberry Research in Chatsworth, New Jersey (39.82°N, 74.53°W), the UMass Cranberry Experiment Station in East Wareham, Massachusetts (41.76°N, 71.67°W), and in commercial cranberry beds in Warrens, Wisconsin (44.13°N, 90.49°W). All production practices, such as pest management, fertilizer inputs, and irrigation followed regional commercial standards (Besançon et al. 2021; Ghantous et al. 2021; Guedot et al. 2021).

The methodology and analyses used in these studies were based on the work reported by Patten and Wang (1994). The same methodology was used for Carolina redroot and earth loosestrife studies in New Jersey and bristly dewberry studies in Wisconsin. The Carolina redroot studies were conducted over the course of three seasons, whereas bristly dewberry and earth loosestrife studies were conducted in two seasons. In each study season, 40 0.5-m^2 quadrats were located in cranberry beds where the target weed species was the only species present and the cranberry vines visually appeared otherwise healthy and with complete canopy growth. Within each cranberry bed, quadrats were visually placed to include a variety of weed densities ranging from complete absence to the highest level of visually estimated infestation. In Wisconsin, the studies were conducted in cranberry beds planted to the ‘Stevens’ variety, while in New Jersey the varieties were ‘Ben Lear’ for Carolina redroot and ‘Stevens’ for earth loosestrife studies.

Smaller quadrats and fewer samples (30 in 2018 and 24 in 2019) were used in the polytrichum moss study in Massachusetts since harvesting the moss mat down to the soil level and separating moss plants intertwined among cranberry vines requires significant time for each sample. In this case, individual quadrats measuring 0.09 m^2 were randomly placed on Stevens beds with patchy moss infestations to capture a gradient of moss cover from none to 100%. All plant material within the quadrat was harvested to the soil level using hand-held clippers. The samples were placed into individual bags by quadrat and brought to the laboratory for separation of cranberry vines, berries and moss vegetation.

Weed and cranberry sampling was conducted within a few days of cranberry harvest in mid-September through mid-October in each season. Weed species data collection included population density, biomass, and groundcover for Carolina redroot, earth loosestrife and bristly dewberry, and biomass for polytrichum moss in Massachusetts. Weed groundcover was visually estimated in each 0.5-m^2 quadrant. Cranberry yield measures included total fresh berry biomass and berry number, which subsequently were used to calculate average berry weight. Additionally, berry quality measures included the percent rotted fruit, berry color rated visually on a scale of 0 (no red color) to 10 (complete red color across the entire berry; in Wisconsin only), total anthocyanin (TAcy; New Jersey only) and percent insect-damaged fruit (in New Jersey only; no insect-damaged fruit was noted in Wisconsin or Massachusetts

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press

Table 1. Regression slope and statistical significance among years for Carolina redroot, earth loosestrife, bristly dewberry, and polytrichum moss in cranberry.

Weed species	Regression variables (x, y)	Year	Number	Regression slope	Slope standard error	P-value
Carolina redroot	Weed density, marketable berry yield	2018	40	−7.84	1.4	<0.001
		2019	40	−5.55	1.1	<0.001
		2020	40	−5.58	1.5	<0.001
	Weed biomass, marketable berry yield	2018	40	−21.26	5.6	<0.001
		2019	40	−23.24	4.6	<0.001
		2020	40	−21.94	5.9	<0.001
	Weed groundcover, marketable berry yield	2018	40	−34.28	7.2	<0.001
		2019	40	−28.95	5.7	<0.001
		2020	40	−31.46	8.5	<0.001
Earth loosestrife	Weed density, marketable berry yield	2019	40	−3.93	2.3	0.09
		2020	40	−1.08	1.5	0.48
	Weed biomass, marketable berry yield	2019	40	−14.95	9.4	0.12
		2020	40	−8.36	5.3	0.12
	Weed groundcover, marketable berry yield	2019	40	−25.95	17.8	0.15
		2020	40	−7.73	5.4	0.16
Bristly dewberry	Weed groundcover, marketable berry yield	2018	40	−23.22	6.9	0.002
		2019	40	−22.18	4.4	<0.001
	Weed biomass, marketable berry yield	2018	40	−35.58	10.3	0.001
		2019	40	−45.10	10.9	<0.001
Polytrichum moss	Weed biomass, marketable berry yield	2018	30	−2.68	1.0	0.03
		2019	24	−6.19	1.5	0.003

studies). Total marketable fruit excluded rotted or insect-damaged fruit and fruit <0.95 cm in diameter. Cranberry vine and weed biomass were dried in an oven at 60 C for 3 d, then weighed to determine dry biomass.

Linear regression was used to explore the relationship between weed biomass, groundcover, or density and marketable cranberry yield in each study year as reported by Patten and Wang (1994). Data were subject to ANOVA to determine the significance level of the regression coefficients. Additionally, two-sided *t*-tests were used to compare regression slopes among years within a weed species as a measure of the consistency in weed interference impacts across study years. Data were then pooled across study years for each species, and Pearson correlation coefficients were used to determine the significance of the relationships between weed interference (density, groundcover or biomass) and cranberry quality parameters (i.e., color, insect-damaged fruit, vine biomass, etc.).

Results and Discussion

Regression Analysis

Weed density, groundcover, and dry biomass were regressed against marketable cranberry yield for each study year and weed species. All linear regressions for Carolina redroot, bristly dewberry, and polytrichum moss were significant at the $P < 0.05$ level, and nine of these 12 regressions were highly significant at $P \leq 0.001$ (Table 1). For Carolina redroot, the slope for weed density regressed against marketable berry yield ranged from −5.55 to −7.84 across the three study years, indicating a temporally and spatially consistent relationship where each Carolina redroot plant reduced cranberry yield by an average of 6.3 g $m{-}^{2}$. Weed groundcover was also strongly related to marketable berry yield in each year (Table 1).

Additionally, two-sided *t*-tests were conducted to compare the regression slopes between study years to further explore whether the results were consistent enough to be reliable indicators of the relationship between weed interference and cranberry yield in a way that is useful to growers, cranberry processors and crop consultants. In this case, there were no differences in the slopes among three study years when Carolina redroot weed density or groundcover were regressed against cranberry yield (Table 2).

In the relationship between Carolina redroot biomass and cranberry yield, the regression slope was similar in 2018, 2019, and 2020 (−21.26, −23.22, and −21.94, respectively; Tables 1 and 2), indicating that in these three study years, each gram of Carolina redroot dry biomass reduced cranberry yield by an average of 22.1 g. While Carolina redroot density, groundcover, and biomass were very consistently related to cranberry yield across all three study years, from a practical standpoint, weed density or groundcover are good measurement choices in that they require the practitioner to simply count weeds or visually estimate cover in a square meter instead of harvesting the weed, drying, and then weighing biomass at a later date.

In contrast, the relationship between earth loosestrife measurements and marketable cranberry yield was not consistent between years nor statistically significant in any case (Table 1). For example, when earth loosestrife groundcover was regressed against marketable berry yield, regression slope estimates ranged from −25.95 in 2019 to −7.73 in 2020, with P-values of 0.15 and 0.16, respectively.

The relationship between visual estimation of bristly dewberry groundcover and cranberry yield was very consistent between the two study years. One percent bristly dewberry groundcover reduced cranberry yield by −23.2 g and −22.2 g in 2018 and 2019, respectively; a remarkably consistent relationship given the subjective nature of visual estimations as well as the viny nature of *Rubus* species growth (Table 1). The P-value for the two-sided *t*-test comparing regression slopes between the two study years was 0.9 (Table 2). The relationship between bristly dewberry biomass and cranberry yield was also consistent and indicated a severe impact from weed competition, ranging from a 35.6 g cranberry yield loss from 1 g bristly dewberry biomass in 2018 to a 45.1 g yield loss in 2019 (Table 1). These slopes were statistically similar between years, suggesting a consistent and reliable relationship (Table 2).

The regression relationship between polytrichum moss biomass and marketable cranberry yield was still statistically significant, but less so than the relationships for Carolina redroot and bristly dewberry. Additionally, the regression slope for this relationship

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press

Table 2. Comparison of regression slopes among years in cranberry for Carolina redroot and earth loosestrife in New Jersey, bristly dewberry in Wisconsin, and polytrichum moss in Massachusetts.[a]

Weed species	Regression variables (x, y)	Year comparison	Number	P-value
Carolina redroot	Weed density, marketable berry yield	2018 vs. 2019	80	0.20
		2019 vs. 2020	80	0.99
		2018 vs. 2020	80	0.26
	Weed biomass, marketable berry yield	2018 vs. 2019	80	0.78
		2019 vs. 2020	80	0.86
		2018 vs. 2020	80	0.93
	Weed groundcover, marketable berry yield	2018 vs. 2019	80	0.56
		2019 vs. 2020	80	0.81
		2018 vs. 2020	80	0.80
Earth loosestrife	Weed density, marketable berry yield	2019 vs. 2020	80	0.30
	Weed biomass, marketable berry yield	2019 vs. 2020	80	0.54
	Weed groundcover, marketable berry yield	2019 vs. 2020	80	0.33
Bristly dewberry	Weed groundcover, marketable berry yield	2018 vs. 2019	80	0.90
	Weed biomass, marketable berry yield	2018 vs. 2019	80	0.53
Polytrichum moss	Weed biomass, marketable berry yield	2018 vs. 2019	54	0.05

[a]Regression slopes were compared using two-sided *t*-tests with a significance level of $P \leq 0.05$.

differed between the 2018 and 2019 study years ($P = 0.05$), with more than double the impact on yield in 2019 than in 2018 (Tables 1 and 2).

The authors hypothesize that there could be several reasons for the less significant and consistent relationship observed with the moss species. First, the biological relationship between a dense and deep matting species such as polytrichum moss may be more complex and less predictable than with other weed species. Mosses have complex ecosystem functions, and for coexisting vascular plants, can act both as beneficial (e.g., increase moisture availability) and inhibitory (e.g., reduce nitrogen availability; Gornall et al. 2011). Overall cranberry yield for the farm where the moss trial was located was 28,245 kg ha^{-1} in 2018 and declined to only 20,400 kg ha^{-1} in 2019. This indicates the crop was experiencing stressors in 2019 not present in 2018 (such as high air temperature, data not shown). It has been documented that biotic and abiotic stressors can significantly impact the competition dynamics between crops and weeds and varies based on plant species (Patterson 1995). We hypothesize that the competition level between moss and cranberry was enhanced by abiotic stressors in 2019, however, more research is needed to understand the details of this relationship.

Additionally, the sample size and number for polytrichum moss was less than for the other studied weed species given the time-consuming nature of harvesting and separating moss plants from cranberry vines deep within the plant community canopy, and this may have reduced the statistical power and consistency of the relationship.

These relationships are presented visually in Figures 1 through 3 for all weed species except earth loosestrife, for which no significant relationships were observed. As noted earlier and in Table 2, all regression slopes compared here (with one exception) were similar between study years, but the intercepts differ quite substantially among years for Carolina redroot and between years for polytrichum moss. For example, the y-intercept for Carolina redroot in 2019 was 3,249 g and 5,347 g in 2020 (Figure 1). This indicates that while cranberry yield was about 40% greater in 2020, the impact of weed competition remained similar. The remarkable consistency between years in using visual estimations of Carolina redroot or bristly dewberry groundcover to estimate cranberry yield are illustrated in

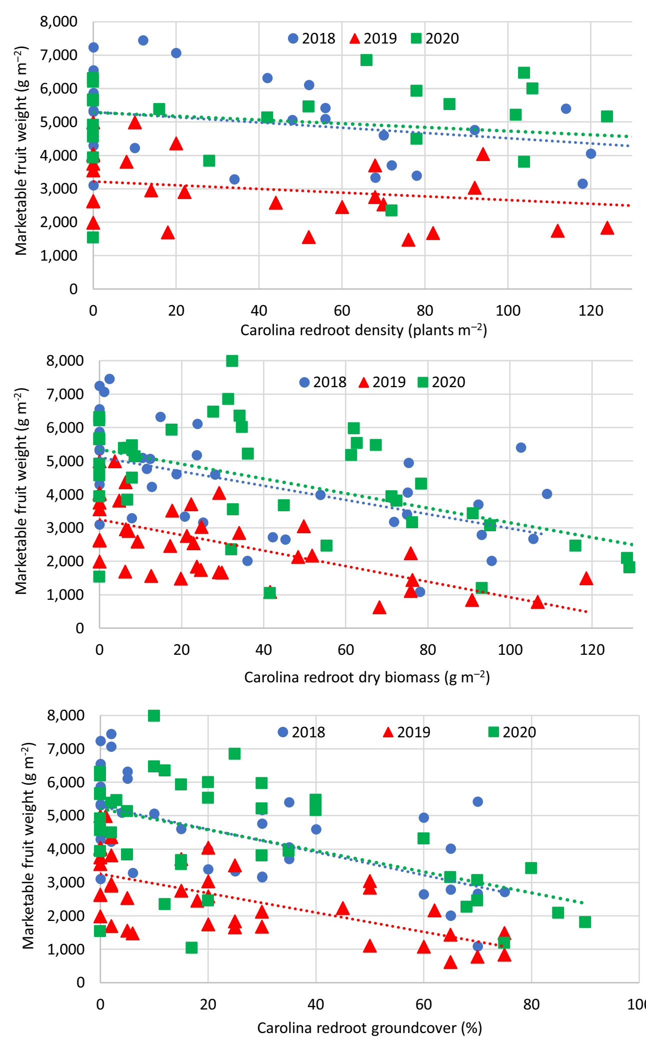

Figure 1. ‘Ben Lear’ cranberry marketable fruit weight relative to Carolina redroot density, dry biomass, and groundcover in 2018, 2019, and 2020 in Chatsworth, New Jersey.

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press

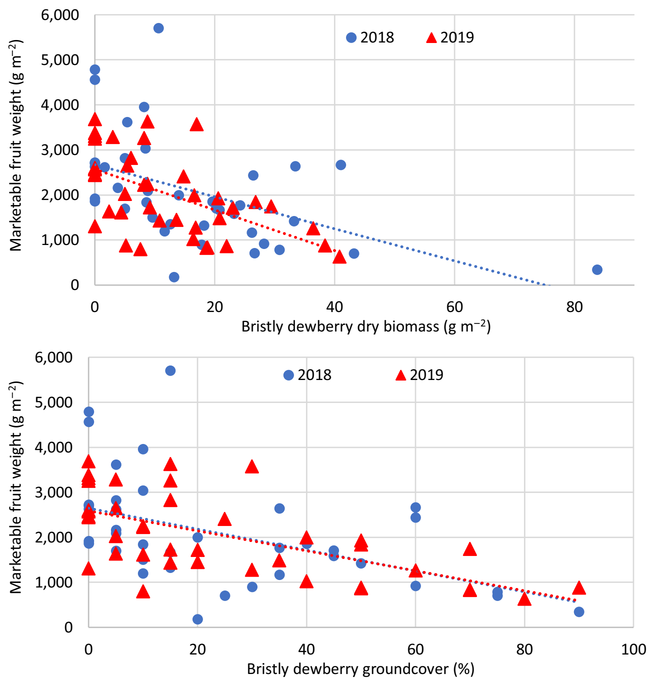

Figure 2. 'Stevens' cranberry marketable fruit weight relative to bristly dewberry dry biomass and groundcover in 2018 and 2019 in Warrens, Wisconsin.

Figures 1 and 2. In future research, it would be interesting to explore whether this simple and feasible method could be applied to additional cranberry weed species, particularly with the recent availability of mobile digital imaging applications that could reduce subjectivity.

Relationship between Cranberry Quality and Weed Interference

Data were combined across study years to explore the relationship between cranberry quality parameters of local interest and weed interference from these three species. Anecdotally, growers have suggested that weeds harbor damaging insects, increase crop canopy humidity and water retention leading to increased fruit rot and cover the cranberry canopy in a way that shields cool fall air from aiding red berry color development, but those notions had not been studied or objectively documented. In this work, we found that cranberry fruit rot was only correlated with weed interference in one case—with bristly dewberry groundcover, which supports the grower notion mentioned above.

For Carolina redroot, berry number was highly correlated with both weed biomass and density ($P < 0.001$; Table 3). Interestingly, the percentage of insect-damaged fruit was also strongly positively correlated with Carolina redroot weed biomass and density (Table 3 and Figure 4). Scars at the surface of the fruits associated with the absence of feeding damage on cranberry vines indicated that injuries were caused by sparganothis fruitworm (*Sparganothis sulfureana* Clemens; L. Wells-Hansen, personal communication). Previous studies carried out in New Jersey and Massachusetts have shown that sparganothis fruitworm can use weeds (such as earth loosestrife) in cranberry beds as a primary host species (Averill and Sylvia 1998). No studies have determined whether Carolina redroot could be a possible primary or secondary host species for this pest. Carolina redroot foliage is known to host larva of the mottled duskywing moth (*Erynnis martialis* Scudder), and

Table 3. Pearson correlation coefficients for the relationship between various cranberry quality parameters and weed interference.[a]

Weed species	Cranberry quality parameter, weed interference variable	Number	Pearson correlation coefficient
Carolina redroot	Cranberry number, weed biomass	120	<0.001
	Cranberry % rot, weed biomass	120	0.26
	Cranberry % insect damage, weed biomass	120	<0.001
	Cranberry total anthocyanin, weed biomass	120	0.42
	Cranberry number, weed density	120	<0.001
	Cranberry % rot, weed density	120	0.45
	Cranberry % insect damage, weed density	120	<0.001
	Cranberry total anthocyanin, weed density	120	0.21
Bristly dewberry	Cranberry number, weed biomass	80	0.93
	Cranberry % rot, weed biomass	80	0.22
	Cranberry color, weed biomass	80	<0.001
	Cranberry number, weed groundcover	80	0.39
	Cranberry % rot, weed groundcover	80	0.001
	Cranberry color, weed groundcover	80	0.002
Polytrichum moss	Cranberry % rot, weed biomass	54	0.73
	Cranberry vine biomass, weed biomass	54	0.002

[a]Data were combined across study years.

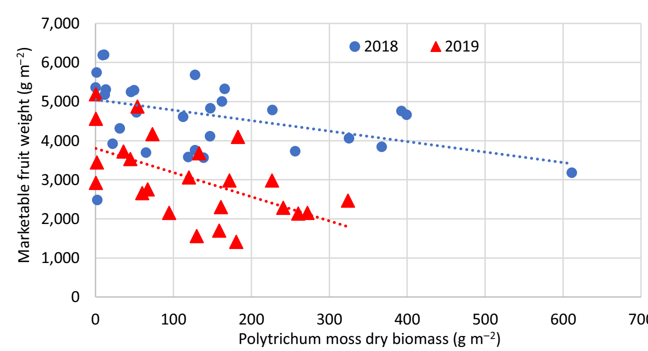

Figure 3. 'Stevens' cranberry marketable fruit weight relative to polytrichum moss dry biomass in 2018 and 2019 in East Wareham, Massachusetts.

Carolina redroot flowers attract many pollinators, including butterflies (Les 2020). Egg masses of spotted fireworm (*Choristoneura parallela* Robinson), an important pest of cranberry in New Jersey where larvae feed on fruits and leaves, have also been found on the upper leaf surface or floral stem of Carolina redroot (D. Schiffhauer, personal communication). Future studies should be conducted to determine whether Carolina redroot plants might be a secondary host for sparganothis larvae or whether Carolina redroot blooming from late June to mid-July might attract sparganothis adults that appear during the same period (de Lange and Rodiguez-Saona 2015). Carolina redroot leaves usually extend above the cranberry canopy and could intercept air-applied insecticides, thereby reducing insecticide effectiveness and increasing the proportion on insect-damaged berries. Because Carolina redroot cannot be controlled with agricultural practices traditionally associated with cranberry cropping (Besançon 2021), it is therefore important to develop

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press

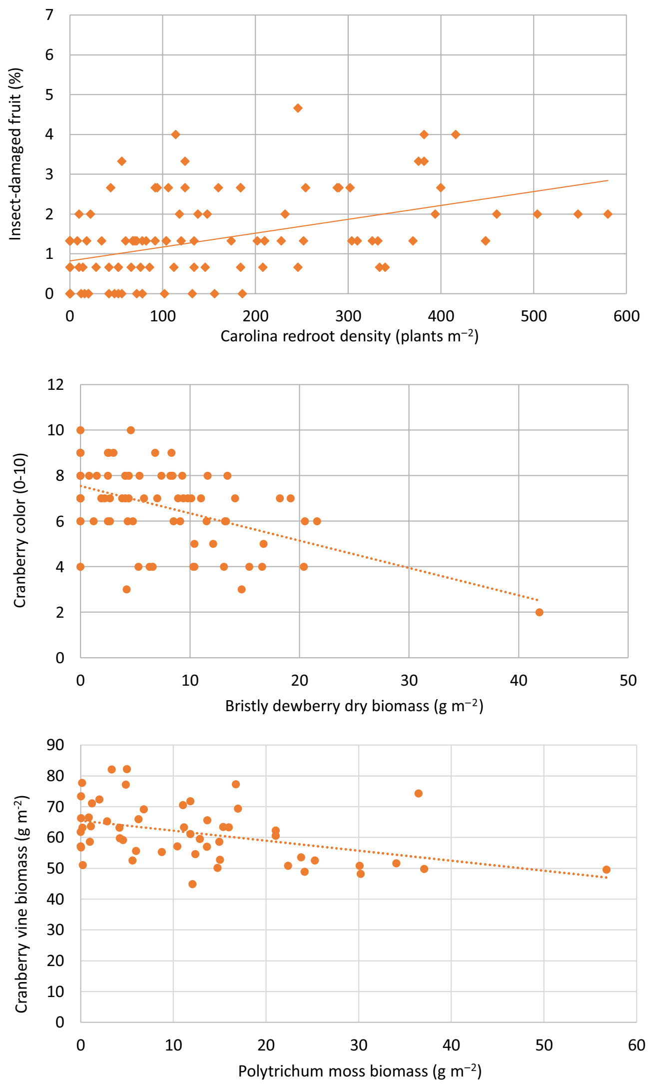

Figure 4. Regression of selected cranberry quality and weed parameters. Carolina redroot studies were conducted in 'Ben Lear' cranberry in New Jersey (2018 to 2020), bristly dewberry studies were conducted in 'Stevens' cranberry in Wisconsin (2018 and 2019), and polytrichum moss studies were conducted in Stevens cranberry in Massachusetts (2018 and 2019). Data were combined across study years.

management strategies based on early detection and use of effective residual and postemergence herbicides.

Wisconsin cranberry growers have often noted observations of substantial cranberry color loss associated with dewberry growth above the cranberry canopy (J. Colquhoun, personal communication). This work strongly supports that notion, where cranberry color loss was significantly correlated with both bristly dewberry biomass and groundcover (Table 3 and Figure 4).

In Massachusetts, it was noted that cranberry vine biomass significantly decreased with increased polytrichum moss biomass ($P = 0.002$; Figure 4). Although moss competition was not directly tested in this study, research in lowbush blueberry (*Vaccinium angustifolium* Ait.), a closely related crop with similar growth habit to cranberry, examined polytrichum moss competition dynamics (Percival and Garbary 2012). Manually removing 0% (control), 33%, 66%, and 100% of moss resulted in blueberry stem densities that were 184%, 248%, and 361% greater than the untreated control in the vegetative stage and 167%, 371%, and 555% greater in the reproductive stage, respectively, indicating that moss was physically competing with blueberry for space rather than growing in areas where blueberry growth was sparse. For cranberry, the relationship between decreased cranberry biomass and increased moss biomass closely resembles the observed trend of decreased fruit yield with increased moss biomass as seen in lowbush blueberry.

Practical Applications and Next Steps

In a practical sense, there are two primary ways that this information can be used to inform cranberry weed management. First, these studies provide objective information that can be used to educate growers, consultants, agrichemical registrants, and regulators about the impacts of weeds on cranberry yield and quality. Prior to this work and in the absence of related studies, anecdotal observations and prognostication were the only data sources. For example, in a 2019 survey of Wisconsin cranberry growers, 15% of respondents indicated that they felt their weed pressure had no impact on cranberry yield and 64% thought their yield loss was 10% or less (Wisconsin State Cranberry Growers Association, unpublished data). In simple calculations using the data presented here, maximum yield loss in the presence of bristly dewberry ranged from 75% to 95% in the two study years, and where Carolina redroot was present maximum yield loss was 79% to 81% across the three study years. This suggests that yield loss from weeds such as these is not only much greater than what growers assume but also quite consistent among production years, particularly with Carolina redroot.

Second, this information can be used to economically prioritize management efforts based on the weed species and extent of infestation. For example, bristly dewberry groundcover was a consistent and reliable observation to use in yield impact estimations as noted in this work. In 2018, the regression presented here would indicate that 20% bristly dewberry groundcover was related to a 4,640 kg ha^{-1} yield loss. Using an estimate of US\$0.78 kg^{-1} based on the 2020 processed crop value (USDA-NASS 2021), this yield loss would cost the grower US\$3,630 ha^{-1}, suggesting a high priority for management. Additionally, the long-term colonizing nature of bristly dewberry is a common driver of cranberry bed renovation, which compounds the financial impact as noted above.

The studies presented here indicate that the relationship between weed interference and cranberry yield can be reasonably estimated with feasible field trials and is consistent among production years. Given these observations, the work presented here would not need repeating over time to remain reliable unless there were significant changes in the production system, such as variety advancements that change crop growth habit or phenology. With that in mind, cranberry growers and related processing industries would benefit from expanding this work to include additional weed species, creating a data library that could be used to prioritize research and management efforts.

Acknowledgments. We thank Baylee Carr and the crew at the P.E. Marucci Center for their help collecting data. We also thank the Wisconsin Cranberry Board, the New Jersey Blueberry and Cranberry Research Council, the Cranberry Institute, and Ocean Spray Cranberries, Inc. for their financial support of this work. No conflicts of interest are declared.

References

Averill AL, Sylvia MM (1998) Pages 52–56 *in* Cranberry insects of the Northeast - A guide to identification, biology and management. Amherst: University of Massachusetts Extension

Besançon TE, Oudemans PV, Rodriguez-Saona C (2021) 2021 Commercial cranberry pest control recommendations for New Jersey. New Brunswick: Rutgers New Jersey Agricultural Experiment Station. 18 p

Besançon TE (2019) Carolina redroot (*Lachnanthes caroliniana*) vegetative growth and rhizome production as affected by environmental factors and planting depth. Weed Sci 67:572–579

Colquhoun J, Roper T, Sulman J (2009) Weeds of the cranberry marsh. Madison: University of Wisconsin Extension and Wisconsin Cranberry Board. 206 p

de Lange E, Rodriguez-Saona C (2015) Sparganothis Fruitworm: A Pest of Cranberry in New Jersey. https://njaes.rutgers.edu/fs1249/. Accessed: October 20, 2021

Else MJ, Sandler HA, Schluter S (1995) Weed mapping as a component of integrated pest management in cranberry production. HortTechnol 5:302–305

Ghantous KM, Sylvia MM, Gauvin D, eds. (2021) Cranberry Chart Book: Management Guide for Massachusetts. Amherst: University of Massachusetts Extension. 104 p

Gordon M (2009) Costs of renovating MA cranberry farms-final report. UMass cranberry research station reports and surveys. https://scholarworks.umass.edu/cranberry_research_repts/25/. Accessed: August 19, 2021

Gornall JL, Woodin SJ, Jónsdóttir IS, van der Wal R (2011) Balancing positive and negative plant interactions: how mosses structure vascular plant communities. Oecologia 166:769–782

Guedot C, Colquhoun J, Nice G, Holland L (2021) Cranberry pest management in Wisconsin. UW Extension Bulletin A3276. https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A3276-2021.pdf. Accessed: August 18, 2021

Hoekstra B, Neill C, Kennedy C (2020) Trends in the Massachusetts cranberry industry create opportunities for the restoration of cultivated riparian wetlands. Restor Ecol 28:185–195

Les DH (2020) Pages 345–348 *in* Aquatic Monocotyledons of North America - Ecology, Life History, and Systematics. Boca Raton, FL: CRC Press

Neron R, Deland JP, Drolet I, Painchaud J (2013) Guide D'identification des Mauvaises Herbes de la Canneberges. Quebec: Centre de Reference en Agriculture et Agroalimantaire du Quebec (CRAAQ)

Patten K, Wang J (1994) Cranberry yield and fruit quality reduction caused by weed competition. HortSci 29:1127–1130

Patterson DT (1995) Effects of environmental stress on weed/crop interactions. Weed Sci 43:483–490

Percival D, Garbary D (2012) Moss competition dynamics and suppression technologies in wild blueberry production. Int J Fruit Sci 12:135–145

Sandler HA (2018) Weed management in cranberry: a historical perspective and a look to the future. Agriculture 8:1–20

Sandler HA, Dalbec L, Ghantous KM (2015) Identification guide for weeds in cranberries. Quebec: Centre de référence en agriculture et agroalimentaire due Québec. 293 pp

Swanton CJ, Harker KN, Anderson RL (1993) Crop losses due to weeds in Canada. Weed Technol 7:537–542

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2021) Noncitrus fruits and nuts: 2020 summary. https://downloads.usda.library.cornell.edu/usda-esmis/files/zs25x846c/sf269213r/6t054c23t/ncit0521.pdf. Accessed: August 18, 2021

[USDA-NRCS] U.S. Department of Agriculture–Natural Resources Conservation Service (2021) USDA Plants Database. https://plants.sc.egov.usda.gov/home. Accessed: August 31, 2021

https://doi.org/10.1017/wet.2022.28 Published online by Cambridge University Press