Weed Technology

www.cambridge.org/wet

Research Article

Cite this article: Besançon TE and Erndwein L (2024) Integrating sequential applications of residual and postemergence herbicides for controlling Carolina redroot (*Lachnanthes caroliniana*) in cranberry beds. Weed Technol. **38**(e77), 1–9. doi: 10.1017/wet.2024.30

Received: 2 November 2023
Revised: 31 January 2024
Accepted: 30 April 2024

Associate Editor:
Katherine Jennings, North Carolina State University

Nomenclature:
Dichlobenil; mesotrione; napropamide; norflurazon; Carolina redroot, *Lachnanthes caroliniana* (Lam.) Dandy LAHTI; large cranberry, *Vaccinium macrocarpon* Ait.

Keywords:
Specialty crops; weed control; herbicide injury; yield; Northeast

Corresponding author:
Thierry Besançon;
Email: thierry.besancon@rutgers.edu

Integrating sequential applications of residual and postemergence herbicides for controlling Carolina redroot (*Lachnanthes caroliniana*) in cranberry beds

Thierry E. Besançon[1] and Lindsay Erndwein[2]

[1]Associate Professor, Philip E. Marucci Center for Blueberry and Cranberry Research and Extension, Department of Plant Biology, Rutgers University, Chatsworth, NJ, USA and [2]Research Associate, Philip E. Marucci Center for Blueberry and Cranberry Research and Extension, Genetic Improvement of Fruits and Vegetables Laboratory, U.S. Department of Agriculture–Agricultural Research Service, Chatsworth, NJ, USA

Abstract

Carolina redroot (LAHTI) is a perennial weed of New Jersey cranberry beds. It is associated with "stand opening" areas that result from fairy ring dieback or other conditions of natural and anthropogenic origin. LAHTI accounts for significant yield reduction through direct competition with cranberry for nutritional resources. Field experiments were conducted from 2017 to 2022 on 'Ben Lear' and 'Early Black' cranberry beds in Chatsworth, NJ, to determine 1) the efficacy of residual herbicides labeled for use on cranberry, and subsequently, 2) to evaluate the value of overlapping preemergence applications of napropamide and postemergence applications of mesotrione for LAHTI control while minimizing crop phytotoxicity. Treatments in the first experiment included preemergence applications of dichlobenil or norflurazon at 2.2 and 4.5 kg ha^{-1} and napropamide a 6.7 kg ha^{-1}. In the second trial, napropamide was applied preemergence annually to plots at 6.7 or 10.1 kg ha^{-1} either as a single or as two equally or unequally split applications spaced 30 d apart, followed by or not followed by mesotrione applied postemergence at 280 g ha^{-1} when LAHTI leaves emerged above the cranberry canopy. The preemergence herbicides dichlobenil applied at 4.5 kg ha^{-1} and napropamide provided ≥48% LAHTI control and ≥40% LAHTI biomass reduction 112 d after treatment (DAT), whereas norflurazon had no significant effect on LAHTI biomass. Less than 4% of crop injury and liquid formulation adapted to chemigation identified napropamide as an effective preemergence herbicide for LAHTI control. In the second trial, napropamide applied at 10.1 kg ha^{-1} followed by an application of mesotrione reduced LAHTI biomass by ≥73%. Splitting napropamide application reduced yield by 36% and berry weight by 12% compared with a single application at the dormant stage. Compared with the nontreated control, a single napropamide application at 10.1 kg ha^{-1} followed by an application of mesotrione increased yield by 38%. Information derived from these studies is already being used by growers to enhance the productivity and profitability of New Jersey cranberry fields.

Introduction

Cranberry (*Vaccinium macrocarpon* L.) is an economically important perennial crop of New Jersey where it has been commercially cultivated since 1835 (Eck 1990). Throughout the United States, more than 15,000 ha and 330 million kg of fruits were harvested in 2022 (USDA-NASS 2022). New Jersey ranked third nationally for cranberry production in 2021 with 1,170 ha harvested, yielding more than 26 million kg of cranberries valued at $23 million, and with 99% of the fruits sold for processing (USDA-NASS 2022). Cranberry is a perennial vine established from unrooted cuttings obtained by pruning productive plantings or rooted plant material produced from true to variety mother stock. Following transplanting, the establishment of the planted bed and the formation of a continuous canopy cover is achieved after 3 to 4 yr through the production of stolons (i.e., runners) by the cranberry vines. The cost of cranberry bed replanting (i.e., renovation) is relatively high, estimated to be a minimum of $62,0000 ha^{-1} for New Jersey cranberry farms in 2022 (L.D. Wells-Hansen, personal communication). Because weed competition may affect cranberry yield and quality (Colquhoun et al. 2022; Patten and Wang 1994), weed control during the cranberry establishment phase remains critical for ensuring a rapid return on bed renovation investment.

The lack of soil cultivation and the persistent nature of the crop favors the development of perennial weed species in cranberry beds (Sandler et al. 2015). Most weed species considered to be of high or very high priority in Massachusetts are perennial species such as bristly dewberry (*Rubus hispidus* L.), cat greenbrier (*Smilax glauca* Walter), earth loosestrife [*Lysimachia*

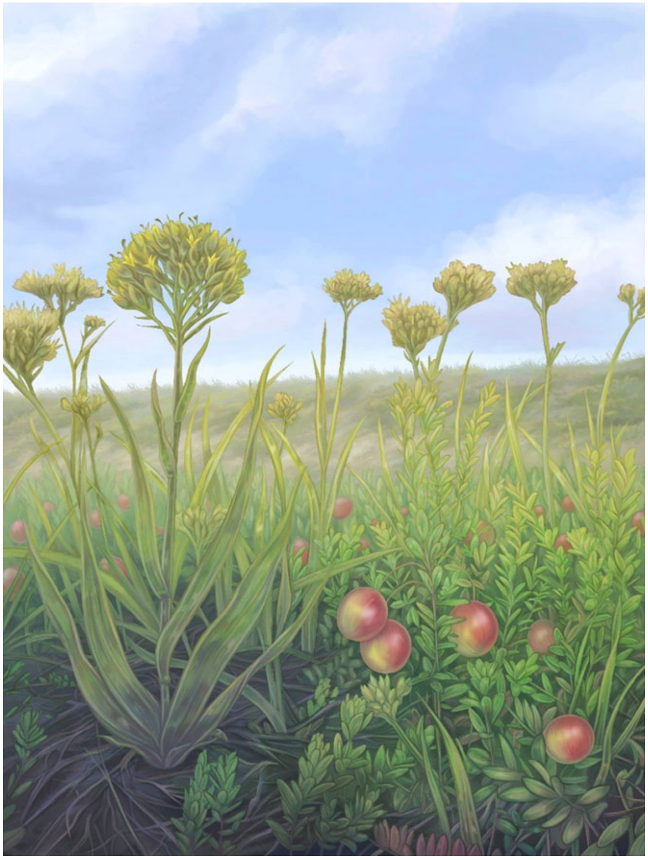

Figure 1. Carolina redroot [*Lachnanthes caroliana* (Lam.) Dandy] establishment in a New Jersey cranberry bed. Illustration by Lindsay Erndwein, 2024.

terrestris (L.) Britton, Sterns & Poggenb.], and broomsedge bluestem (*Andropogon virginicus* L.) (Sandler and Ghantous 2021). Carolina redroot [*Lachnanthes caroliana* (Lam.) Dandy] (LAHTI) is a frequent perennial herbaceous weed of New Jersey cranberry beds (Figure 1) where sandy acidic soils (pH 4 to 5) and abundant moisture offer optimal growing conditions for this species (Applegate et al. 2012; Besançon 2019a). Unlike many other weed species that are common to all cranberry production areas of the eastern United States, LAHTI is restricted to New Jersey where it reaches the northerly point of its distribution (USDA-NRCS 2018). LAHTI establishment in cranberry beds is often associated with open areas in new plantings and cranberry canopy openings in established beds (Besançon 2019a). Once established, LAHTI progressively colonizes the entire cranberry bed and causes significant fruit yield and quality reduction. Colquhoun et al. (2022) indicated that each gram of LAHTI dry biomass decreased cranberry yield by 22 g on average in 20-yr-old beds, and that the proportion of insect-damaged berries was positively correlated with LAHTI dry biomass and density. They hypothesized that the effectiveness of insecticides applied to cranberry could be reduced because of spray interception by LAHTI leaves extending above cranberry canopy. Weed control strategies in new plantings and established cranberry beds rely exclusively on the use of conventional herbicides due to the continuous crop cover that prevents the use of nonchemical options except hand-weeding (Besançon 2022; Guedot et al. 2024; Sandler and Ghantous 2021). Additionally, LAHTI is remarkably plastic in terms of environmental factors that affect its development, such as soil water content, flooding, or depth of shoot emergence (Besançon 2019a). Information on LAHTI control with herbicides is mostly restricted to greenhouse studies. Meyers et al. (2013b) noted that terbacil and hexazinone (categorized as a Group 5 herbicide by the Weed Science Society of America [WSSA]) applied preemergence at 1.8 kg ha^{-1} and 2.2 kg ha^{-1}, respectively, decreased LAHTI shoot and root/rhizome dry weight by 64% to 92% while flumioxazin (WSSA Group 14) at 430 g ha^{-1}, hexazinone at 1.1 kg ha^{-1}, and *S*-metolachlor (WSSA Group 15) at 1.4 kg ha^{-1} had no significant effect. However, none of these preemergence herbicides are registered for use on cranberry beds. Previous research has documented the efficacy of some postemergence herbicides for LAHTI control. Glyphosate (WSSA Group 9) at 1.26 kg ha^{-1}, paraquat (WSSA Group 22) at 560 g ha^{-1}, and glufosinate (WSSA Group 10) at 660 g ha^{-1} provided 59% to 72% and 73% control of LAHTI shoots and 91% control of LAHTI rhizomes, 63 d after treatment (DAT) (Meyers et al. 2013a). Paraquat and glufosinate are not labeled for use on cranberry because they would induce severe crop injury, whereas glyphosate is used for controlling perennial weeds such as red maple (*Acer rubrum* L.) or glaucous greenbrier (*Smilax glauca* Walter) (Besançon 2022). LAHTI shoot density frequently exceeding 100 plants m^{-2} (Colquhoun et al. 2022) would prevent effective wiping of glyphosate. Mesotrione (WSSA Group 27) at 280 or 560 g ha^{-1} demonstrated 91% and 98% control, respectively, of LAHTI shoots 63 DAT, and reduced its rhizome dry weight by 84% and 89%, respectively, (Besançon 2019b). Mesotrione is already labeled for broadcast application to cranberry beds at 280 g ha^{-1} per application and at an annual maximum rate of 560 g ha^{-1} (Anonymous 2018).

Under field conditions, the primary objectives of the work presented here were to 1) evaluate LAHTI control in response to application of preemergence herbicides labeled for use on cranberry, and 2) identify effective LAHTI control strategies based on sequential applications of preemergence and postemergence herbicides while minimizing cranberry phytotoxicity and maintaining crop profitability.

Materials and Methods

Studies were conducted in 2017 through 2022 with commercial cranberry beds (Pine Island Cranberry Co., Inc.) in Chatsworth, NJ. Two cranberry beds infested with LAHTI were selected for conducting field trials: an 'Early Black' bed planted in 1938 (hereafter referred to as E3; 39.72°N, 74.52°W) and a 'Ben Lear' bed planted in 2003 (hereafter referred to as B40; 39.75°N, 74.52°W). At the E3 location the soil was an Atsion sand (sandy, siliceous, mesic Aeric Alaquods) with 84% sand, 5% silt, 1% clay, and 8.6% organic matter, pH 4.2. At B40 the soil was a Berryland mucky sand (sandy, siliceous, mesic Typic Alaquods) with 93% sand, 4% silt, 3% clay, and 4.7% organic matter, pH 4.2 Both beds had dense and evenly distributed LAHTI populations at the start of the study, averaging 145 and 96 plants m^{-2} in B40 and E3, respectively. All production practices followed New Jersey commercial standards (Besançon et al. 2022). For both studies, individual plots were 3.3 m^2 and uniformly covered with cranberry vines.

Residual Herbicide Screening

Field trials evaluating LAHTI control in response to preemergence herbicide applications were established in 2017 at E3 and B40, and

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press

in 2018 at E3. The study was conducted as a randomized complete block design with four replications per treatment. Herbicide treatments consisted of napropamide (Devrinol® 2-XT, United Phosphorus, Inc., King of Prussia, PA; WWSA Group 0) at 6.75 kg ha^{-1}, norflurazon (Evital® 5G; AMVAC Chemical Corp., Newport Beach, CA; WSSA Group 12) and dichlobenil (Casoron® 4G; United Phosphorus, Inc.; WSSA Group 29) at 2.25 and 4.5 kg ha^{-1}. A nontreated weedy control was also included. Treatments were applied prior to LAHTI emergence on spring dormant (SD) cranberry vines, characterized by tight red buds. A CO_2-pressurized backpack sprayer fitted with TeeJet XR8004 flat-fan nozzles (Spraying Systems Co., Glendale Heights, IL) was calibrated to broadcast the spray solutions at 235 L ha^{-1} at 193 kPa, corresponding to the volume delivered by cranberry cantilevered spray booms. Applications occurred on April 28, 2017, and on April 17, 2018. Herbicides were activated by watering plots with 1.9 cm of overhead irrigation within 48 h of application. LAHTI weed control was visually estimated at 28, 56, 84 and 112 DAT on a 0 (no control) to 100% (death of all plants) scale, based on a composite estimation of stand density reduction, growth inhibition, and foliar injury (Frans et al. 1986). LAHTI aboveground biomass was collected 122 DAT from one 0.21-m^2 quadrat established in the center of each plot by pruning plants at the soil surface. Individual samples were then placed in paper bags and dried at 65 C for 96 h. LAHTI was the only weed species present during the study. On September 26, 2017, and September 27, 2018, berries were harvested from two 0.28-cm^2 quadrats adjacent to the biomass quadrat and in areas where vines had not been previously subjected to trampling. Both samples were subsequently combined and sorted out in the laboratory to determine the weight of marketable berries and individual berry weight.

Sequential Herbicide Applications and LAHTI Reinfestation

An experiment was conducted from 2019 to 2022 at the E3 and B40 locations to assess LAHTI control and cranberry tolerance in response to sequential herbicide applications. A different area than the evaluation study of preemergence herbicides was chosen within each bed. The study was a randomized complete block design with three replications per treatment. Each individual plot received the same herbicide treatment for three consecutive years in 2019, 2020, and 2021. Herbicide treatments included napropamide (Devrinol DF-XT) applied at 6.7 or 10.1 kg ha^{-1} either as a single application at the SD stage within 1 wk of the winter flood removal, or as a split application between the SD stage and 30 d later at the hook stage when flower pedicels lengthen and begin to droop. Split applications were either equally split with 50% of the napropamide rate applied at each stage (3.35 or 5.05 kg ha^{-1}) or unequally split with 67% of the napropamide rate applied at the SD stage (4.5 or 6.75 kg ha^{-1}) and 33% at the hook stage (2.2 or 3.35 kg ha^{-1}). Single napropamide treatments were applied either alone or followed by (fb) mesotrione (Callisto®; Syngenta Crop Protection, Greensboro, NC) at 280 g ha^{-1} applied mid-June to coincide with LAHTI leaves emerging above the crop canopy. All split applications of napropamide were followed by an application of mesotrione at 280 g ha^{-1}. Mesotrione applications included a nonionic surfactant (Induce; Helena Professional Products, Collierville, TN) at 2.5 ml L $^{-1}$. Depending on the year, napropamide at the SD and hook stages was applied between April 17 and May 4, and between May 17 and June 1, respectively. Each year, mesotrione applications occurred between June 12 and June 17. Napropamide was applied and activated as described in the preemergence herbicides evaluation study; mesotrione was applied using a CO_2-pressurized backpack sprayer equipped with TeeJet XR8004 flat-fan nozzles (Spraying Systems Co.) and calibrated to broadcast 187 L ha^{-1} at 152 kPa. For comparison purposes, a nontreated weedy control was also included.

Visual estimates of LAHTI control were performed 50 and 110 d after initial treatment (DAIT) using a 0% (no control) to 100% (death of all plants) scale, based on a composite estimation of weed density reduction, growth inhibition, and foliar injury (Frans et al. 1986). The first and second ratings were conducted 1 wk before and 8 wk after the postemergence application, respectively. Using the same methodology as previously described, LAHTI shoot density and aboveground dry biomass, and berry yield and quality were recorded 160 DAIT.

No herbicide treatment was applied in 2022, but both fields were monitored to evaluate LAHTI reinfestation following 3 yr of repeated herbicide applications. LAHTI shoot density and aboveground dry biomass, and cranberry marketable yield were collected on September 20 at B40 and on September 21 at E3.

Statistical Analysis

Statistical analyses and figure generation were performed using R software version 4.2.3 (R Core Team 2023). The hypothesis that differences exist in variables (LAHTI control, density and biomass, marketable cranberry yield) between fixed factors (year, plot location, herbicide) was tested using one-way ANOVAs with the *aov* function in the R STATS package (R Core Team 2023). Normality was examined qualitatively using quantile-quantile plots and quantitatively using Shapiro-Wilk normality tests ($P \geq 0.05$) with default parameters. Residuals were checked for normality using Kolmogorov-Smirnov tests in the function *ols_test_normality* of the OLSRR R package version 0.5.3 (Hebbali 2023). Summary statistics stratified by factors were generated using functions of R package TABLE1 version 1.4.2 (Rich 2023). Pairwise differences were detected with Tukey's honestly significant difference test using the function *TukeyHSD* in the AGRICOLAE R package version 1.3.5 (de Mendiburu 2023). Orthogonal contrasts were developed for the sequential herbicide applications and LAHTI reinfestation studies to assess the effects of two napropamide rates, the inclusion of mesotrione as opposed to no-postemergence herbicide, and the splitting of the napropamide application. Significance for all tests were defined as $P \leq 0.05$. Orthogonal contrasts figures were constructed using the GGPLOT2 visualization R package version 3.3.5 (Wickham 2016).

Results and Discussion

Residual Herbicide Screening

LAHTI control following an application of norflurazon was less than 20% regardless of applied rate or timing of evaluation (Table 1). Conversely, dichlobenil applied at 2.2 and 4.5 kg ha^{-1} provided 45% and 55% control of LAHTI 56 DAT, respectively, and 36% and 48% control, respectively, 112 DAT, with no significant effect of the rate applied. If LAHTI control at 56 DAT was not different between napropamide and norflurazon applications (≤30%), later ratings at 84 and 112 DAT indicated greater control with napropamide that reached 48% and 50%, respectively, and was comparable to control with dichlobenil at 4.5 kg ha^{-1}. Visual ratings were confirmed by LAHTI dry biomass data that showed no more than 17% biomass reduction compared with the

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press

Table 1. In-season Carolina redroot control and dry biomass 112 DAT in response to residual preemergence herbicides applied during the spring dormant cranberry bud stage at two locations in Chatsworth, New Jersey, in 2017 and 2018.[a–c]

Herbicide	Rate	Carolina redroot control			Biomass reduction
		56 DAT	84 DAT	112 DAT	
	kg ai ha^{-1}	———	%	———	%
Nontreated	–	0 b	0 d	0 b	–
Dichlobenil	2.2	45 a	38 bc	36 a	45 bc
Dichlobenil	4.5	55 a	53 a	48 a	69 c
Napropamide	6.7	30 ab	48 ab	50 a	41 bc
Norflurazon	2.2	17 ab	4 cd	1 b	0 a
Norflurazon	4.5	17 ab	7 cd	1 b	17 ab

[a]Abbreviation: DAT, days after treatment.
[b]Control was rated on a 0 (no control) to 100% (death of all plants) scale.
[c]Data were pooled across locations and years. Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($P \leq 0.05$).

Table 2. Cranberry injury and marketable yield in response to residual preemergence herbicides applied during the spring dormant cranberry bud stage at two locations in Chatsworth, New Jersey, in 2017 and 2018.[a–c]

Herbicide	Rate	Cranberry injury			Marketable yield
		56 DAT	84 DAT	112 DAT	
	kg ai ha^{-1}	———	%	———	× 1,000 kg ha^{-1}
Nontreated	–	0[c] b	1 c	0 b	9.9
Dichlobenil	2.2	6 a	7 a	2 a	9.3
Dichlobenil	4.5	7 a	8 a	2 a	11.1
Napropamide	6.7	4 a	4 b	1 ab	9.3
Norflurazon	2.2	0 b	2 bc	0 b	10.4
Norflurazon	4.5	0 b	1 c	0 b	11.2

[a]Abbreviation: DAT, days after treatment.
[b]Injury (chlorosis + stunting) was rated on a 0 (no injury) to 100% (crop death) scale with 5% increments.
[c]Data were pooled across locations and years. Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($P \leq 0.05$).

nontreated control, regardless of application rate. By contrast, LAHTI dry biomass was reduced 69% with dichlobenil at 4.5 kg ha^{-1} and 43%, on average, following dichlobenil at 2.2 kg ha^{-1} or napropamide at 6.7 kg ha^{-1}.

Cranberry injury ranging from 4% to 7% was noted 56 DAT following dichlobenil and napropamide applications, regardless of rate, whereas no injury was noted with norflurazon (Table 2). Although significant injury was noted with napropamide and both rates of dichlobenil, injury did not exceed 8% with any of the treatments during the rating period. No effect of preemergence application was observed on marketable fruit yield regardless of herbicide or rate.

Dichlobenil injury to cranberry vines has been observed in previous studies. Sandler (2013) reported that dichlobenil applied at 1.8 and 2.7 kg ha^{-1} (40% and 60% of the maximum label rate, respectively) during stages of cranberry flower development or during bloom had a greater probability of causing interveinal chlorotic injury. However, no negative yield effect following crop recovery was observed by late summer. LAHTI is listed among species controlled by norflurazon (Anonymous 2021), yet minimal to no control was noted in the present study when it was used at the recommended chemigation rate of 4.5 kg ha^{-1} for the sandy soils in New Jersey cranberry beds. Napropamide provided significant reduction of LAHTI biomass by the end of the summer and can be easily chemigated, unlike granular formulated dichlobenil and norflurazon. Therefore, napropamide is an ideal preemergence choice for cranberry growers who are interested in controlling LAHTI. Napropamide was selected as the preemergence herbicide for the sequential herbicide application study evaluating strategies associating preemergence and postemergence herbicides and subsequently presented.

Sequential Herbicide Applications

In the absence of a significant location by treatment interaction, LAHTI control data were pooled over locations. LATHI control 50 DAIT was not affected by preemergence treatments, averaging 29% in 2019, 27% in 2020, and 82% in 2021 (Table 3). Contrast analysis showed that napropamide at 10.1 kg ha^{-1} provided greater LAHTI control 50 DAIT than at 6.7 kg ha^{-1}, averaging 24% and 31% in 2020, and 78% and 86% in 2021, respectively (data not shown). Regardless of splitting rate, a single application of napropamide at 10.1 kg ha^{-1} following winter flood removal gave better LATHI control 50 DAIT than a split treatment, averaging 35% in 2020 and 89% in 2021, as opposed to 26% and 84%, respectively (data not shown). While LATHI control 110 DAIT did not differ between napropamide applied at 6.7 or 10.1 kg ha^{-1} in 2019 and 2020, a single application at 10.1 kg ha^{-1} fb mesotrione postemergence averaged 88% control in 2021 compared with less than 70% for napropamide treatments at 6.7 kg ha^{-1} fb mesotrione applied postemergence (Table 4). Averaged across napropamide splitting and postemergence applications, LAHTI control 110 DAIT in 2021 was 81% with napropamide at 10.1 kg ha^{-1} compared with 68% at the 6.7 kg ha^{-1} rate (Figure 2). The inclusion of mesotrione postemergence at 280 g ha^{-1} increased LAHTI control 110 DAIT each year compared to an early-season single application of napropamide (Figure 3).

Herbicide treatments had no effect on LATHI shoot density 110 DAIT in 2019 (Table 4). Except for the equal splitting of napropamide at the 6.7 kg ha^{-1} rate, all other napropamide fb mesotrione treatments applied postemergence in 2020 reduced LAHTI shoot density by 60% on average, compared with the nontreated control. In 2021, inclusion of mesotrione postemergence with napropamide at 6.7 or 10.1 kg ha^{-1} decreased LAHTI shoot density by 55% and 68%, respectively, compared with the nontreated control. In 2020 and 2021, similar LAHTI shoot density was recorded for both the nontreated control and plants that were sprayed with napropamide preemergence alone. The inclusion of mesotrione applied postemergence decreased LAHTI shoot density by 55% compared to napropamide applied alone regardless of rate (Figure 4). For treatments that included mesotrione applied postemergence in 2019, higher LAHTI shoot density ($P = 0.0217$) was noted when napropamide was applied at 6.7 kg ha^{-1} (417 plants m^{-2}) than at 10.1 kg ha^{-1} (330 plants m^{-2}). However, this difference did not persist beyond the first year of napropamide application. A greater reduction of cumulated LAHTI dry biomass was observed for all napropamide treatments at 10.1 kg ha^{-1} fb mesotrione applied postemergence (75%) than for napropamide applied alone at 6.7 or 10.1 kg ha^{-1} (40%). Averaged over napropamide rate and splitting distribution, LATHI cumulated dry biomass averaged 89 g m^{-2} when preemergence applications were fb mesotrione postemergence compared to 187 g m^{-2} in the absence of postemergence application, which corresponds to 69% and 35% biomass reduction, respectively, compared with the nontreated control. When napropamide was applied at 10.1 kg ha^{-1} fb mesotrione applied postemergence LAHTI cumulated dry

Table 3. Carolina redroot control in response to an annual preemergence application of napropamide followed by mesotrione applied postemergence at two locations in Chatsworth, NJ, from 2019 to 2021.[a,b]

		Carolina redroot control					
		50 DAIT			110 DAIT		
Treatment[c]	Rate	2019	2020	2021	2019	2020	2021
	kg ai ha^{-1}	%					
Napropamide LR single	6.7	36	28	78	0[c] b	8 b	46 e
Napropamide LR single fb mesotrione	6.7 + 0.28	33	26	83	42 a	42 a	67 cd
Napropamide LR equal split fb mesotrione	3.35 + 3.35 + 0.28	24	18	74	38 a	39 a	69 b-d
Napropamide LR unequal split fb mesotrione	4.5 + 2.2 + 0.28	23	24	78	40 a	41 a	69 b-d
Napropamide HR single	10.1	30	36	86	5 b	11 b	56 de
Napropamide HR single fb mesotrione	10.1 + 0.28	27	34	90	43 a	37 a	82 ab
Napropamide HR equal split fb mesotrione	5.05 + 5.05 + 0.28	30	29	84	43 a	44 a	88 a
Napropamide HR unequal split fb mesotrione	6.75 + 3.35 + 0.28	30	23	84	39 a	44 a	76 a-c

[a]Abbreviations: DAIT, days after initial treatment; fb, followed by; HR, napropamide high rate at 10.1 kg ha^{-1}; LR, napropamide low rate at 6.7 kg ha^{-1}.
[b]Data were pooled across locations in the absence of significant treatment × location interaction. Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($P \leq 0.05$).
[c]A nonionic surfactant at 2.5 ml L^{-1} was included when mesotrione was applied postemergence at 280 g ha^{-1}.

Table 4. Carolina redroot density and cumulated dry biomass at harvest in response to an annual application of napropamide followed by mesotrione at two locations in Chatsworth, NJ, from 2019 to 2021.[a,b]

		Shoot density			
Treatment[c]	Rate	2019	2020	2021	Biomass reduction[d]
	kg ai ha^{-1}	plants m^{-2}			%
Nontreated	–	359	393 a	369 a	–
Napropamide LR single	6.7	433	342 ab	324 a	41 c
Napropamide LR single fb mesotrione	6.7 + 0.28	390	175 bc	178 bc	59 bc
Napropamide LR equal split fb mesotrione	3.35 + 3.35 + 0.28	450	231 a-c	158 c	62 bc
Napropamide LR unequal split fb mesotrione	4.5 + 2.2 + 0.28	412	148 c	161 bc	66 ab
Napropamide HR single	10.1	396	410 a	296 ab	40 c
Napropamide HR single fb mesotrione	10.1 + 0.28	370	110 c	119 c	73 a
Napropamide HR equal split fb mesotrione	5.05 + 5.05 + 0.28	294	177 bc	111 c	78 a
Napropamide HR unequal split fb mesotrione	6.75 + 3.35 + 0.28	329	172 c	129 c	74 a

[a]Abbreviations: fb, followed by; HR, napropamide high rate at 10.1 kg ha^{-1}; LR napropamide low rate at 6.7 kg ha^{-1}.
[b]Data were pooled across locations in the absence of significant treatment × location interaction. Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($P \leq 0.05$).
[c]Nonionic surfactant applied at 2.5 ml L^{-1} was included with mesotrione postemergence at 280 g ha^{-1}.
[d]Biomass reduction is presented as percent reduction relative to the nontreated control.

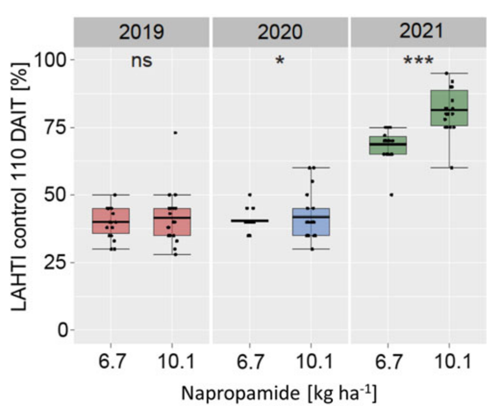

Figure 2. Orthogonal contrast for Carolina redroot (LAHTI) control 110 d after initial treatment (DAIT) in response to annual preemergence applications of napropamide at 6.7 and 10.1 kg ha^{-1} followed by a postemergence application of mesotrione at 280 g ha^{-1} at two locations in Chatsworth, NJ, from 2019 to 2021. Data were pooled across locations, napropamide splitting distribution, and mesotrione postemergence application. Significance was determined according to Tukey's HSD test ($P \leq 0.05$). P-value ranges and respective significance codes are as follows: ***, $0 < P < 0.001$; **, $0.001 < P < 0.01$; *, $0.01 \leq P < 0.05$; and ns, $P > 0.05$. The horizontal line within boxplots represents the mean value for each group.

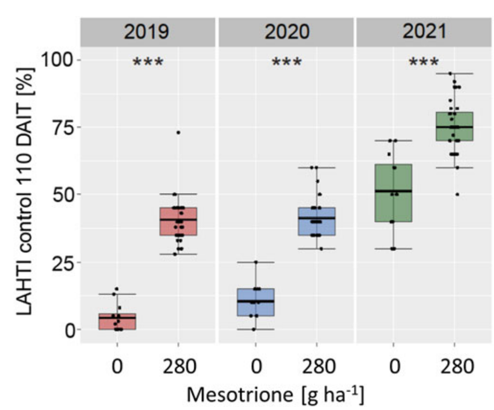

Figure 3. Orthogonal contrast for annual Carolina redroot (LAHTI) control 110 d after initial treatment (DAIT) in response to mesotrione postemergence at two locations in Chatsworth, NJ, from 2019 to 2021. Data were pooled across locations, napropamide rate, and spitting distribution. Significance was determined according to Tukey's HSD test ($P \leq 0.05$). P-value ranges and respective significance codes are as follows: ***, $0 < P < 0.001$; **, $0.001 < P < 0.01$; *, $0.01 \leq P < 0.05$; and ns, $P > 0.05$. The horizontal line within boxplots represents the mean value for each group.

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press

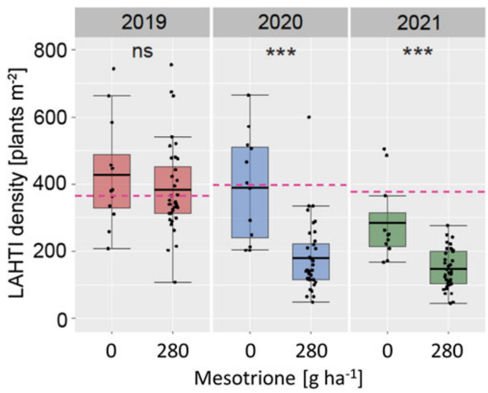

Figure 4. Orthogonal contrast for annual Carolina redroot (LAHTI) shoot density at the end of the growing season in response to mesotrione applied postemergence at two locations in Chatsworth, NJ, from 2019 to 2021. Data were pooled across locations, napropamide rate, and splitting distribution. Significance was determined according to Tukey's HSD test ($P \leq 0.05$). P-value ranges and respective significance codes are as follows: ***, $0 < P < 0.001$; **, $0.001 < P < 0.01$; *, $0.01 \leq P < 0.05$; and ns, $P > 0.05$. The horizontal line within boxplots represents the mean value for each group.

biomass was reduced by 75% compared with a 62% reduction at the 6.7 kg ha^{-1} rate (P = 0.0042).

Because of a significant interaction with locations (P = 0.0174), cumulated marketable yield data were separated by location (Table 5). In the oldest and least productive E3 bed, herbicide treatments had no significant effects on cranberry marketable yield (P = 0.5914). In the younger and more productive B40 bed, higher marketable yield was noted with a single postemergence application of napropamide at 6.7 or 10.1 kg ha^{-1} fb mesotrione than for the nontreated control, corresponding to a 32% yield increase. In the absence of mesotrione applied postemergence, only plots treated with napropamide at 10.1 kg ha^{-1} produced significantly higher yield (28%) than the nontreated control. Orthogonal contrast analysis showed that splitting the napropamide application fb mesotrione applied postemergence, regardless of napropamide rate or split distribution, reduced cumulated marketable yield by 31% compared with a single application of napropamide at 6.7 or 10.1 kg ha^{-1} fb a postemergence application of mesotrione. Because single and split applications of napropamide provided similar LAHTI control and stand density reduction, we hypothesize that yield reduction resulted from crop phytotoxicity in response to napropamide applied at the hook stage. Napropamide application to cranberry field is not recommended following the beginning of spring growth (Anonymous 2012). Shawa (1982) indicated 23% and 30% cranberry phytotoxicity following napropamide applied at 10 and 20 kg ha^{-1} at the bud swell stage in April, whereas similar rates applied to dormant vines in March did not cause any injury. On average, splitting of napropamide at the 10.1 kg ha^{-1} rate also reduced individual berry weight by 13% compared with a single application at the same rate. Overall, the percentage of marketable berries for napropamide split-applied at 6.7 and 10.1 kg ha^{-1} was, respectively, 4% and 7% lower than for a single application at the same rate.

LAHTI Reinfestation

In the absence of a significant interaction between locations and treatments, data collected in 2022 were pooled over locations (Table 6). LAHTI shoot density remained 50% to 72% lower when mesotrione applied postemergence was included when compared with the nontreated control. Averaged over postemergence treatments, LAHTI shoot density was 23% greater in plots treated with napropamide at 6.7 kg ha^{-1} than at 10.1 kg ha^{-1} (P = 0.0463). For both napropamide rates and regardless of splitting, LAHTI shoot density was 52% to 68% lower when mesotrione was applied postemergence compared with a standalone application of napropamide. Averaged over postemergence applications, LAHTI dry biomass decreased by 63% in plots sprayed with napropamide at 10.1 kg ha^{-1} compared with 49% when napropamide was applied at 6.7 kg ha^{-1} (P = 0.0066). Adding mesotrione postemergence to the herbicide program reduced LAHTI dry biomass by 60% and 70% following napropamide applied at 6.7 and 10.1 kg ha^{-1}, respectively, compared with a reduction in dry mass of ≤21% when standalone napropamide was applied. Overall, LAHTI control lasted beyond the period of herbicide application as long as napropamide applied preemergence was followed by mesotrione applied postemergence. No detrimental effect on cranberry marketable yield was noted with previous herbicide applications.

These results indicated that napropamide applied alone at rates labeled for use on cranberry had no effect on LAHTI shoot density but could significantly reduce LAHTI development and biomass accumulation. This may effectively prevent the formation of LAHTI seedheads, which frequently impedes cranberry harvest or causes the presence of unacceptable foreign material during cranberry processing (L.D. Wells-Hansen, personal communication). However, inclusion of mesotrione significantly reduced both LAHTI shoot density and biomass, regardless of napropamide rate applied preemergence. Our results agree with those reported by Sandler (2017), who observed 84% reduction of total weed biomass in Massachusetts cranberry beds following 2 yr of napropamide applied preemergence at 3.36 or 5.04 kg ha^{-1} fb mesotrione applied postemergence at 210 g ha^{-1}, whereas napropamide applied alone resulted in only 58% weed biomass reduction. Control with napropamide applied alone was similar to that reported from a greenhouse study (Meyers et al. 2013b) with hexazinone and terbacil applied preemergence at 2.2 and 1.8 kg ha^{-1}, respectively, which controlled LAHTI 40% 140 DAT. However, LAHTI control did not exceed 5% with flumioxazin and *S*-metolachlor, illustrating the difficulty of controlling this perennial species with residual herbicides currently labeled for use on *Vaccinium* crop species. As previously demonstrated in greenhouse evaluations of postemergence herbicides (Besançon 2019b), mesotrione controlled LATHI by >75% when supplemented with napropamide applied to cranberry at the highest labeled use rate (10.1 kg ha^{-1}). However, the greatest level of LAHTI control was observed in 2021 following 3 yr of repeated herbicide applications. This is consistent with conclusions drawn by Meggitt and Aldrich (1959) who stated that LAHTI control with amitrole (WSSA Group 34) is "effective in the second- and third-year following treatment which indicates control is primarily a problem of eliminating existing plants and not a problem of controlling seedlings which arise from seed". Reducing the sprouting capacity of the LAHTI rhizome is critically important to achieve control of this species, which has an extremely low seed germination rate of <0.5% even though seed production is estimated to exceed 100,000 seeds m^{-2} (Boughton et al. 2016).

Despite demonstrating good efficacy and crop safety, preemergence broadcast applications of napropamide fb mesotrione applied postemergence should be reserved to cranberry beds where a large proportion of the acreage is infested with LAHTI. Prior field research has shown that spot applications of mesotrione at 1,120 g ha^{-1} in mid-June before LAHTI initiates the formation of the flower stem (i.e., bolting) provided 93% reduction of LAHTI dry

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press

Table 5. Cranberry cumulated yield, individual berry weight and percentage of marketable berries in response to annual application of napropamide preemergence followed by mesotrione applied postemergence at two locations in Chatsworth, NJ, from 2019 to 2021.[a,b]

Treatment[c]	Rate	Cumulated marketable yield		Berry weight	Marketable berries
		B40	E3		
	kg ai ha^{-1}	—× 1,000 kg ha^{-1}——		g	%
Nontreated	–	65.7 cd	30.1	1.34 ab	79 a-c
Napropamide LR single	6.7	83.3 a-c	38.5	1.34 ab	81 ab
Napropamide LR single fb mesotrione	6.7 + 0.28	83.5 ab	46.4	1.40 a	78 bc
Napropamide LR equal split fb mesotrione	3.35 + 3.35 + 0.28	61.5 cd	38.6	1.34 ab	77 c
Napropamide LR unequal split fb mesotrione	4.5 + 2.2 + 0.28	60.3 d	42.7	1.32 ab	77 c
Napropamide HR single	10.1	84.4 ab	35.7	1.41 a	84 a
Napropamide HR single fb mesotrione	10.1 + 0.28	90.6 a	50.0	1.38 a	82 ab
Napropamide HR equal split fb mesotrione	5.05 + 5.05 + 0.28	55.5 d	46.9	1.21 b	78 bc
Napropamide HR unequal split fb mesotrione	6.75 + 3.35 + 0.28	61.2 d	36.7	1.23 b	77 c

[a]Abbreviations: fb, followed by; HR, napropamide high rate at 10.1 kg ha^{-1}; LR napropamide low rate at 6.7 kg ha^{-1}.
[b]Data were pooled across locations in the absence of significant treatment × location interaction. Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($P \leq 0.05$).
[c]Nonionic surfactant applied at 2.5 ml L^{-1} was included with mesotrione applied postemergence at 280 g ha^{-1}.

Table 6. Averaged Carolina redroot shoot density, dry biomass, and cranberry fruit yield in 2022 following 3 consecutive years (2019–2021) of annual herbicide applications targeting Carolina redroot at two locations in Chatsworth, NJ.[a,b]

Treatment[c]	Rate	Carolina redroot		Cranberry marketable yield
		Shoot density	Biomass reduction	
	kg ai ha^{-1}	No. m^{-2}	%	×x 1,000 kg ha^{-1}
Nontreated	–	323 a	–	11.7
Napropamide LR single	6.7	309 ab	14 c	18.3
Napropamide LR single fb mesotrione	6.7 + 0.28	160 bc	62 a	14.5
Napropamide LR equal split fb mesotrione	3.35 + 3.35 + 0.28	145 c	65 a	18.5
Napropamide LR unequal split fb mesotrione	4.5 + 2.2 + 0.28	139 c	54 ab	11.7
Napropamide HR single	10.1	310 ab	21 bc	15.8
Napropamide HR single fb mesotrione	10.1 + 0.28	94 c	76 a	20.1
Napropamide HR equal split fb mesotrione	5.05 + 5.05 + 0.28	90 c	82 a	19.1
Napropamide HR unequal split fb mesotrione	6.75 + 3.35 + 0.28	117 c	72 a	13.6

[a]Abbreviations: fb, followed by; HR, napropamide high rate at 10.1 kg ha^{-1}; LR napropamide low rate at 6.7 kg ha^{-1}.
[b]Data were pooled across locations in the absence of significant treatment x location interaction. Means within a column followed by the same letter are not significantly different from each other according to Tukey HSD test ($P \leq 0.05$).
[c]Nonionic surfactant applied at 2.5 ml L^{-1} was included with mesotrione postemergence at 280 g ha^{-1}.

biomass by the end of the growing season without reducing cranberry yield compared with only 37% when the same rate of mesotrione was applied during LAHTI bloom (Besançon 2020). The same study also demonstrated that control was <70% with mesotrione applied at 560 g ha^{-1} at bolting, suggesting that broadcast application of mesotrione at 280 g ha^{-1} would result in less LAHTI control. Since the maximum use rate for mesotrione on cranberry should not exceed 280 g ha^{-1} per application and 560 g ha^{-1} per season (Anonymous 2023), localized spot applications of mesotrione at 1,120 g ha^{-1} could be considered for controlling LAHTI infestations that do not exceed 25% of the cranberry acreage.

Cranberry is tolerant to mesotrione applied at rates greater than the 280 g ha^{-1} labeled use rate (Majek and Ayeni 2003; Sandler and Ghantous 2008). Recently, New Jersey and Massachusetts received authorization to apply mesotrione for spot treatments of cranberry through a Special Local Need registration under Section 24(c) of the Federal Insecticide, Fungicide, and Rodenticide Act. This Special Local Need authorizes mesotrione to be used at rates up to 5.6 g ai L^{-1} to control dodder (*Cuscuta gronovii* Willd.) or woody weeds such as poison ivy [*Toxicodendron radicans* (L.) Kuntze] (Anonymous 2023; Ghantous and Sandler 2015). LAHTI preferentially colonizes areas of cranberry beds where the crop canopy is sparse following vine death caused by fairy ring (*Helicobasidum* sp.) disease (Polashock et al. 2017) or anthropic factors such as drainage ditches or crop injury resulting from glyphosate wick applications. Thus, localized spot treatment with mesotrione at an early stage of LAHTI establishment may result in effective control at a lower cost than broadcasting napropamide and mesotrione through chemigation or cantilevered boom applications. Current recommendations for control of fairy ring disease include drench applications (80,000 L ha^{-1}) of azoxystrobin and fenbuconazole fungicides between the bud break and rough neck stages, slightly later than residual herbicides are typically applied at the dormant vine stage (Oudemans 2022). We hypothesize that drenching of cranberry fields with a fungicide may cause herbicides to leach out of the upper soil layers and reduce their efficacy at controlling weed emergence in open areas of cranberry beds. Consequently, mesotrione spot-applied later in the season would be a better option for controlling weeds in areas where fungicides are drenched for managing fairy ring disease.

The number of herbicides labeled for use on cranberry remains limited to only 18 active ingredients, and mesotrione is the only labeled herbicide that can be broadcast for postemergence control

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press

Figure 5. 'Early Black' cranberry beds infested with Carolina redroot on September 23, 2021, in Chatsworth, NJ. The bed on the right side of the earthwork was untreated, whereas bed on the left side was annually treated preemergence with napropamide at 10.1 kg ai ha^{-1} followed by mesotrione applied postemergence at 280 g ai ha^{-1} in 2020 and 2021. Both beds had similar Carolina redroot infestation before herbicides were applied.

of sedges and some broadleaf species (Besançon 2022; Sandler 2018). It is therefore frequently sprayed by cranberry growers for controlling a diversity of weed species, and concerns have arisen regarding overuse of this herbicide on cranberry and the risk of resistance development (Sandler and Ghantous 2021). Furthermore, it is critically necessary to evaluate alternative herbicides that could be potentially used postemergence on cranberry. Since 2009, resistance to mesotrione has been documented for pigweed species such as Palmer amaranth (*Amaranthus palmeri* S. Watson), tall waterhemp [*A. tuberculatus* (Moq.) J. D. Sauer], and redroot pigweed (*A. retroflexus* L.) in Illinois, Iowa, Kansas, Nebraska, North Carolina, and Ontario (Heap 2023). To reduce selection pressure and herbicide resistance imposed by repeated use of a single herbicide, most researchers recommend using multiple effective modes of action through herbicide rotations, tank mixtures, and sequential applications (Norsworthy et al. 2012). In a greenhouse study, Meyers et al. (2013a) reported no effective control of LAHTI shoots but a 54% reduction in root and rhizome dry weight with halosulfuron applied postemergence at 40 g ha^{-1}. During the summer of a nonbearing year in crops of lowbush blueberry (*Vaccinium angustifolium* Aiton), White (2021) noted 66% to 100% control of perennial narrow-leaved goldenrod [*Euthamia graminifolia* (L) Nutt.] with flazasulfuron spot-applied postemergence at 0.18 g L^{-1} and ≤32% crop injury 42 DAT. Future studies should evaluate herbicides that inhibit acetolactate synthase that could control LAHTI while minimizing injury to cranberry vines. In addition to evaluating new herbicidal options for LAHTI control, research is also currently being conducted in New Jersey by Rowan University in partnership with Rutgers University to develop an artificial intelligence software that will allow an aerial drone to fly over cranberry bogs and perform early LAHTI detection and create a map of affected areas. If successful, this technology could be integrated with applicator drones. Overall, the use of applicator drones may contribute to significantly reducing the volume of herbicides being used and improving the environmental and economic sustainability of New Jersey cranberry farming through higher crop productivity and berry quality.

Practical Implications

LAHTI remains a significant contributor to quantitative and qualitative yield losses for New Jersey cranberry production as demonstrated in previous published studies (Colquhoun et al. 2022). Available literature on LAHTI control is mostly restricted to North Carolina highbush blueberry crops (Meyers et al. 2013a, 2013b) and to herbicides not labeled for use on cranberry. Results of the present study demonstrated that a LAHTI management strategy based on a preemergence application of napropamide at 10.1 kg ha^{-1} (while cranberry vine is dormant) fb a timely application of mesotrione postemergence (before LAHTI bolting) provided significant control of this troublesome weed while increasing cranberry marketable yield after 3 yr of repeated applications. Napropamide applied alone at 6.7 or 10.1 kg ha^{-1} reduced LAHTI biomass, but it did not provide long-term control. Splitting a napropamide application at the 10.1 kg ha^{-1} rate fb mesotrione applied postemergence provided as good LAHTI control as a single application of napropamide but it caused severe yield reduction. Data generated through this research helped to support the development of a fact sheet that highlights current recommendations for LATHI control in New Jersey cranberry beds (Besançon and Carr 2021). New Jersey cranberry growers have already begun implementing this new management strategy and are reporting significant reduction of LAHTI coverage and better fruit yield in cranberry beds where napropamide and mesotrione have been repeatedly applied (Figure 5). However, new research questions are also emerging. For example, bed sanding is a cultural practice that promotes the successful rooting of cranberry stolons but has been reported to result in a greater number of LAHTI shoots in the following season (M. Haines, personal communication). Future research will investigate LAHTI response, and the adaptation of management strategies defined in this study following sanding of cranberry beds.

Acknowledgments. We thank Dr. Lindsay Wells-Hansen, Dan Schiffhauer, Wesley Bouchelle, and Baylee Carr for providing technical support. We also thank William Haines Jr. and Michael Haines with Pine Island Cranberry Co. for allowing this long-term study to take place on their 130-yr-old farm in Chatsworth, NJ.

Funding. Funding for this research was provided by the Rutgers New Jersey Agricultural Experiment Station, the New Jersey Blueberry and Cranberry Research Council, and Ocean Spray Cranberries, Inc.

Competing Interests. The authors declare they have no competing interests.

References

Anonymous (2012) Devrinol® herbicide label. King of Prussia, PA: United Phosphorus, Inc. 9 p
Anonymous (2018) Callisto® herbicide label. Greensboro, NC: Syngenta Crop Protection. 40 p
Anonymous (2021) Evital® 5G herbicide label. Newport Beach, CA: AMVAC Chemical Corp. 4 p
Anonymous (2023) Callisto® herbicide Special Local Need label for New Jersey. Greensboro, NC: Syngenta Crop Protection. 2 p
Applegate JE, Little S, Marucci PE (2012) Plants and Animal Products of the Pine Barrens. Pages 25–38 *in* Forman R, ed. Pine Barrens: Ecosystem and Landscape. New York: Academic Press
Besançon TE (2019a) Carolina redroot (*Lachnanthes caroliniana*) vegetative growth and rhizome production as affected by environmental factors and planting depth. Weed Sci 67:572–579
Besançon TE (2019b) Carolina redroot (*Lachnanthes caroliniana*) in cranberry: assessment of shoot and rhizome control with POST herbicides. Weed Technol 33:210–216
Besançon TE (2020) 2020 Weed Management Updates for New Jersey Cranberries. 2020 Cranberry Growers Twilight Meeting. https://rutgers.app.box.com/s/5g6513rohp5on4ppewzhcswvge5hp8se/file/1039485500223. Accessed: October 24, 2023
Besançon TE (2022) Controlling Carolina redroot on cranberry. Page 4 *in* Besançon TE, ed. 2022 Cranberry Pest Control Recommendations for New Jersey. New Brunswick: Rutgers New Jersey Agricultural Experiment Station
Besançon TE, Carr BL (2021) Carolina redroot (*Lachnanthes caroliniana*) identification and control. Rutgers Cooperative Extension Fact Sheet FS1338. New Brunswick: Rutgers New Jersey Agricultural Experiment Station
Boughton EH, Boughton RK, Griffith C, Bernath-Plaisted J (2016) Reproductive traits of *Lachnanthes caroliniana* (Lam.) Dandy related to patch formation following feral swine rooting disturbance. J Torrey Bot Soc 143:265–273
Colquhoun J, Besançon TE, Ghantous KM, Sandler HA (2022) Exploring the influence of weeds on cranberry yield and quality. Weed Technol 36:390–396
de Mendiburu F. (2023). agricolae R-package. https://cran.r-project.org/package=agricolae. Accessed: October 13, 2023
Eck P, ed. (1990) The American Cranberry. New Brunswick: Rutgers University Press. 420 p
Frans R, Talbert R, Marx D, Crowley H (1986) Experimental design and techniques for measuring and analyzing plant responses to weed control practices. Pages 37–38 *in* Camper ND, ed. Research Methods in Weed Science. Champaign, IL: Southern Weed Science Society
Ghantous KM, Sandler HA (2015) Poison ivy management in cranberry. Page 37 *in* Proceedings of the 69th Annual Meeting of the Northeastern Weed Science Society, Williamsburg, Virginia, January 5–8, 2015. https://www.newss.org/proceedings/proceedings-2015.pdf. Accessed: October 24, 2023
Guedot C, Colquhoun J, Nice G, Holland L (2024) Cranberry Pest Management in Wisconsin. UW Extension Bulletin A3276. Madison: University of Wisconsin-Extension. https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A3276_3-19-24.pdf. Accessed: May 2, 2023
Heap I (2023) The international herbicide-resistant weed database online. http://www.weedscience.org. Accessed: October 26, 2023
Hebbali A (2023). *olsrr*: Tools for Building OLS Regression Models. https://olsrr.rsquaredacademy.com. Accessed: October 13, 2023
Majek BA, Ayeni AO (2003) The phytotoxicity and utility of quinclorac, chlorimuron, and mesotrione in cranberries. Page 94 *in* Proceedings of the 57th Annual Meeting of the Northeastern Weed Science Society, Baltimore, Maryland, January 6–9, 2003. https://www.newss.org/proceedings/proceedings_2003_vol57.pdf. Accessed: October 23, 2023
Meggitt WF, Aldrich RJ (1959) Amitrol for control of redroot in cranberries. Weeds 7(3):271–276
Meyers SL, Jennings KM, Monks DW, Ballington JR, Jordan DL (2013a) POST control of Carolina redroot (*Lachnanthes caroliniana*). Weed Technol 27:534–537
Meyers SL, Jennings KM, Monks DW, Jordan DL, Ballington JR (2013b) Effect of PRE and POST herbicides on Carolina redroot (*Lachnanthes caroliniana*) growth. Weed Technol 27:747–751
Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60(SP1):31–62
Oudemans PV (2022) Treating fairy ring on cranberry. Page 6 *in* in Besançon TE, ed. 2022 Cranberry Pest Control Recommendations for New Jersey. New Brunswick: Rutgers New Jersey Agricultural Experiment Station
Patten KD, Wang J (1994) Cranberry yield and fruit quality reduction caused by weed competition. HortScience 29:1127–1130
Polashock JJ, Caruso FL, Averill AL, Schilder AC, eds. (2017) Compendium of Blueberry, Cranberry, and Lingonberry Diseases and Pests. St. Paul, MN: American Phytopathological Society. 231 p
R Core Team. 2023. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org. Accessed: October 23, 2023
Rich B (2023) Package '*table1*'. https://github.com/benjaminrich/table1. Accessed: October 13, 2023
Sandler HA (2013) Response of four cranberry varieties to delayed applications of dichlobenil. Weed Technol 27:108–112
Sandler HA (2017) Repeated applications of mesotrione and napropamide on new cranberry plantings. Weed Technol 31:599–608
Sandler HA (2018) Weed management in cranberries: A historical perspective and a look to the future. Agriculture 8:1–20
Sandler HA, Dalbec L, Ghantous KM, eds. (2015) Identification Guide for Weeds in Cranberries. Québec: CRAAQ, Centre de référence en agriculture et agroalimentaire du Québec. 293 p
Sandler HA, Ghantous KM (2008) Perennial weed control and crop tolerance with mesotrione and topramezone in cranberries. Page 75 *in* Proceedings of the 62nd Annual Meeting of the Northeastern Weed Science Society, Philadelphia, Pennsylvania, January 7–10, 2008. https://www.newss.org/proceedings/proceedings_2008.pdf. Accessed: October 26, 2023
Sandler HA, Ghantous KM (2021) Weed management 2021–2023. Pages 41–67 *in* Ghantous KM, Sylvia MM, Gauvin D, eds. Cranberry Chart Book 2021–2023 Management Guide for Massachusetts. East Wareham: University of Massachusetts Amherst Cranberry Station
Shawa AY (1982) Control of aster (*Aster subspicatus*) and birdsfoot trefoil (*Lotus corniculatus*) in cranberries (*Vaccinium macrocarpon*) with napropamide. Weed Sci 30:369–371
[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2022) QuickStats Database. https://quickstats.nass.usda.gov/results/58C5B41B-2814-3C9C-B617-AFE94E140910. Accessed: April 18, 2022
[USDA-NRCS] U.S. Department of Agriculture–National Resources Conservation Service (2018) PLANTS Profile-*Lachnanthes caroliana* (Lam) Dandy. https://plants.usda.gov/home/plantProfile?symbol=LACA5. Accessed: May 2, 2023
White SN (2021) Evaluation of acetolactate synthase/acetohydroxyacid synthase-inhibiting herbicide spot applications and mesotrione tank mixtures for narrow-leaved goldenrod management in lowbush blueberry. Can J Plant Sci 101:177–187
Wickham H (2016) *ggplot2*: Elegant Graphics for Data Analysis (3e). https://ggplot2-book.org. Accessed; October 13, 2023

https://doi.org/10.1017/wet.2024.30 Published online by Cambridge University Press