An Evaluation of Targeted Spraying for Reducing Herbicide Use in Highbush Blueberry

Lynn M. Sosnoskie[1], Roger B. Batts[2], and Thierry Besançon[3]

KEYWORDS. crop safety, optically guided technology, *Vaccinium corymbosum* L., weed control

ABSTRACT. Herbicides are the most common method for weed control in berry crops, although the evolution of herbicide resistance, worker and crop safety concerns, and regulatory challenges associated with the prevention of off-target movement are driving interest in alternative weed management technologies. Optically guided, targeted spray systems show promise for reducing herbicide use, minimizing crop damage, and expanding weed control options in perennial crops. In 2021 and 2022, field trials were conducted in New Jersey to evaluate the impact of conventional banded and targeted (WEED-IT™ system) herbicide applications on weed control and crop outcomes. Control of common groundsel, horseweed, and common purslane was influenced by herbicide type and application strategy but not by their interaction. Fluroxypyr applied at 280 and 560 g a.e./ha provided similar or better control of common groundsel and common purslane (>90%) compared with the 2,4-D choline and glufosinate (71% to 92%) standards. Similarly, horseweed control with florpyrauxifen-benzyl applied at 30 and 60 g a.e./ha (80% to 91%) matched or exceeded the suppression provided by 2,4-D and glufosinate (62% to 87%). Herbicide applications using the WEED-IT™ system reduced herbicide use by approximately 50% but provided less weed control than the traditional banded method; results likely reflect the effects of crop size and density on spray coverage. Crop injury was primarily observed on new canes, with targeted applications causing slightly more damage than the banded treatments across all observation timings. Stunting of new blueberry canes exceeded 8% at 1 week after application and decreased to less than 1% by 4 weeks after application, compared with a maximum of 3% stunting from banded applications. The greater levels of observed crop damage probably result from the system's inability to distinguish between crops and weeds. Despite the potential of targeted spraying technologies to reduce herbicide use, their effectiveness and safety in perennial crops warrant further research, particularly regarding integration into comprehensive weed-management programs.

Fruit crops are significant contributors to the US agricultural economy, with sales reaching $28.6 billion in 2017 (US Department of Agriculture, National Agricultural Statistics Service 2024). This includes blueberries, which are widely grown in the northeastern United States. According to a recent US Department of Agriculture survey, New Jersey was ranked fifth in the United States for highbush blueberry production in 2023 with 4300 ha harvested, yielding over 22,600 t of fresh market fruits valued at $92 million (US Department of Agriculture, National Agricultural Statistics Service 2024).

The use of synthetic herbicides remains the most common and cost-effective method for controlling weeds along the planted row in fruit production systems (US Department of Agriculture, National Agricultural Statistics Service 2024). Postemergence (POST) herbicide applications for highbush blueberry typically involve continuous spray volumes based on a uniform rate applied across an entire treated area, regardless of weed presence. This approach can result in excessive chemical use in areas that do not require treatment, leading to increased costs. Additionally, concerns about the spread of herbicide-resistant weeds (Hanson et al. 2014; Heap 2024), crop damage caused by herbicide drift or misapplication (Al-Khatib et al. 1992; Besançon et al. 2020; Dintelmann et al. 2020), and the adverse effects on soil microbial communities and earthworm populations are motivating a search for different approaches to weed control (Andersen et al. 2013; Gaupp-Berghausen et al. 2015; Mia et al. 2020; Sánchez-Moreno et al. 2015). Changing public perceptions about pesticide use, worker safety concerns associated with the handling and application of pesticides, and emerging regulatory hurdles related to compliance by the US Environmental Protection Agency (2024) with the Endangered Species Act are additional factors driving interest in reducing herbicide usage.

Alternatives to herbicides in fruit crops include tillage and cultivation, mulches and cover crops, hand weeding, and novel weed control technology (Mia et al. 2020). While advantageous for providing effective weed control in perennial crops, these practices also come with certain drawbacks. For example, cultivation can injure shallow-rooted fruit crops, increase erosion rates, disrupt soil structure, and reduce organic matter content (Gristina et al. 2020). Additionally, cultivation may not be suitable for certain berry crops that grow on hilled beds, such as highbush blueberry, or in areas with rocky soils. The relatively short lifespan of plastic mulches makes them largely unsuitable for many perennial cropping systems. Degradation of these mulches can also lead to the formation of microplastics (Wang et al. 2023), and managing used tarps requires burning, storage, or landfill disposal (Zhang et al. 2021). Cover cropping is recognized as an effective technique for improving soil health in perennial crops (Castellano-Hinojosa and Strauss 2020; Liu et al. 2021; Rodriguez-Ramos et al. 2022), as well as for suppressing weeds (Haring et al. 2023; Tworkoski and Glenn 2012). However, widespread adoption of cover cropping is hampered by potential competition with the main crop for water and nutritional resources, which can result in yield loss (Fang et al. 2021). Hand weeding in specialty crops faces challenges from increasing labor costs, an aging workforce, and uncertainties related to immigration policies (McErlich and Boydston 2014).

In contrast to other alternative weed management strategies, novel weed control technologies, including the use of optically guided (hereafter referred to as "targeted") spraying systems, have received limited attention in perennial crops (Fennimore et al. 2016; Sosnoskie et al. 2022, 2023; Westwood et al. 2018). Unlike continuous spray application, targeted sprayers operate by detecting weeds using real-time sensors and simultaneously applying herbicides only to the plants identified by the system. One strategy for weed sensing involves distinguishing green vegetation from soil backgrounds using differences in reflectance patterns (Coleman et al. 2022). These applications have the potential to reduce waste, lower costs, and lessen the environmental impacts of herbicide use. Use of targeted technology may also enhance adaptability to challenging application conditions such as hot and windy weather, thereby reducing the risk of herbicide drift and potential crop injury (Felton and McCloy 1992). The sensitivity of perennial crops to herbicide damage limits the availability of herbicide options. Implementing targeted spray technology could potentially facilitate the registration of new herbicide modes of action if effective weed control can be achieved while ensuring crop safety.

The Interregional Research Project No. 4 was established in 1963 by the US Department of Agriculture to help facilitate the registration of pesticides, biopesticides, and other pest management technologies for use on specialty crops. The IR-4 Project's Integrated Solutions program addresses pest management challenges in specialty crops by identifying integrated pest management strategies that combine chemical, biological, cultural, and mechanical controls, along with new application technologies, with the goal of developing sustainable integrated pest management systems that can be recommended to growers while meeting environmental and regulatory requirements. A research protocol was established through the IR-4 Project Integrated Solutions program (IR-4 Project 2021) and under the direction of the chemical registrants for assessing crop safety and weed control efficacy of nonlabeled POST herbicides in highbush blueberry using the WEED-IT™ spraying system. Field trials were conducted in New Jersey in 2021 and 2022 to compare the performance of conventional banded and WEED-IT™–based herbicide applications under commercial highbush blueberry production conditions.

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[1]School of Integrative Plant Sciences – Horticulture Section, Cornell AgriTech, New York State Agricultural Experiment Station, 221 Hedrick Hall, Geneva NY, 14456, USA

[2]Principal Weed Science Biologist, IR-4 Project Headquarters, 1730 Varsity Drive, Suite 210, Venture IV, Raleigh, NC 27606, USA

[3]Department of Plant Biology, School of Environmental and Biological Sciences Rutgers, The State University of New Jersey, 59 Dudley Road, New Brunswick, NJ 08901-8525, USA

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T.B. is the corresponding author. E-mail: thierry.besancon@rutgers.edu.

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Materials and methods

Optically guided spray system. The WEED-IT™ Quadro unit (Rometron B.V., Steenderen, The Netherlands, hereafter referred to as WEED-IT™) (Fig. 1A) uses fluorescence technology for chlorophyll detection. The WEED-IT™ produces blue light (450 to 500 nm) fla (Fig. 1B). In reaction, chlorophyll emits a near-IR signal in a process known as "chlorophyll fluorescence" (Visser and Timmermans 1996). The WEED-IT™ sensor detects the amount of near-IR emitted by chlorophyll to differentiate a living plant from its surrounding environment. The entire unit includes four independent photodetectors that control four TG-3.5 spray nozzles (TeeJet Technologies, Glendale Heights, IL, USA) (Fig. 1C). When living plant tissue is detected in one of the zones, the associated nozzle activates to apply a targeted dose of herbicide. The unit was mounted on an all-terrain vehicle (ATV) (Fig. 1D), with sensors and nozzles positioned 84 to 89 cm above the ground, providing an overall detection area width of 102 cm.

Field trial. Trials were conducted in 2021 and 2022 at a commercial blueberry farm near Hammonton, NJ, USA (lat. 39°35′50″N, long. 74°46′01″W). Soil at the site was an Aura sandy loam (coarse-loamy, siliceous, semiactive, mesic Typic Fragiudults) with 64% sand, 22% silt, 14% clay, 0.9% organic matter, and a pH of 4.8. The field was planted with 1-year-old 'Draper' highbush blueberry bushes in 2015; rows were spaced 3 m apart with individual bushes spaced 0.9 m apart within the row. Each year, 670 kg·ha^{-1} of 10N–10P–10K NPK fertilizer was broadcasted in a split application at bloom and 6 weeks later. No herbicide was applied before weed emergence. Blueberry bushes were drip irrigated and maintained using standard practices as recommended by the Commercial Blueberry Pest Control Recommendations for New Jersey (Besançon et al. 2024), except for the experimental herbicide treatments. Individual plots were 9 m long by 1.8 m wide with five bushes per plot.

The trial was designed as a two-factor factorial arrangement in a randomized complete block design with four replications. Main factors were POST herbicide treatments and method of herbicide application (i.e., banded and targeted applications). Herbicides treatments included glufosinate (Rely® 280; BASF Corporation, Research Triangle Park, NC, USA) applied at 1680 g a.i./ha, 2,4-D choline (Embed® Extra; Corteva Agriscience, Indianapolis, IN, USA) at 1600 g a.e./ha, fluroxypyr (Starane® Ultra; Corteva Agriscience) at 280 and 560 g a.e./ha, and florpyrauxifen-benzyl (Loyant®; Corteva Agriscience) at 30 and 60 g a.i./ha. Glufosinate and 2,4-D choline were included as standards; fluroxypyr and florpyrauxifen-benzyl were novel chemistries being evaluated for possible use in blueberry. Spray solutions included ammonium sulfate (ThermoFisher Scientific; Ward Hill, MA, USA) at 3360 g·ha^{-1} plus methylated seed oil (FS MSO Ultra™; Precision Laboratories, Waukegan, IL, USA) at 1870 g·ha^{-1} for glufosinate, and nonionic surfactant (Activator 90; Loveland Products, Greeley, CO, USA) at 470 g·ha^{-1} for all other herbicide treatments. To control annual grasses, clethodim (Select Max®; Valent, San Ramon CA, USA) was added at 100 g a.i./ha to each application of the 2,4-D choline, fluroxypyr, and florpyrauxifen-benzyl application. A nontreated control was also included for comparison.

In accordance with the IR-4 Project protocol IS00002 (IR-4 Project 2021), each herbicide was first applied when emerged weeds were less than 10 to 15 cm high with repeat treatments occurring about 30 d later. The first applications occurred on 27 May 2021 and 25 May 2022. Sequential treatments were made on 20 Jun 2021 and 1 Jul 2022. Herbicides were applied to both sides of the vegetation-free ridge beneath the planted blueberry row using either a CO_2 backpack sprayer fitted with two TeeJet AIUB85025 nozzles (TeeJet Technologies, Glendale Heights, IL, USA) spaced 46 cm apart for the banded application or the WEED-IT™ spraying system conveyed on a Honda ATV for

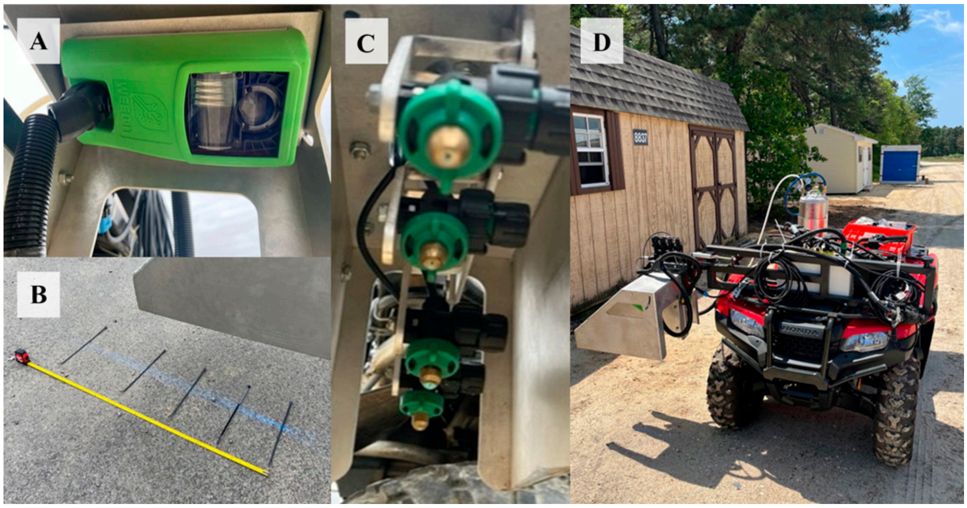

Fig. 1. WEED-IT™ Quadro (Rometron B.V., Steenderen, The Netherlands): blue light (450 to 500 nm) source and fluorescence sensor unit (A), blue light projected to the ground with four individual and independent detection zones (B), pulse width modulation TG-3.5 nozzles (TeeJet Technologies, Glendale Heights, IL, USA) independently controlled by one of the four (C), and the complete spraying system mounted on an ATV (D).

the targeted application. The CO_2 backpack sprayer was calibrated to deliver a volume of 234 L·ha^{-1} at 276 kPa. Application speed was 5 and 8 km·h^{-1} for the CO_2 backpack and WEED-IT™ sprayer, respectively.

Data collection. Weed control by species was estimated on a whole plot level at 1, 2, and 4 weeks after the first application (WAA) and 2 and 4 weeks after the second application (WAB) within each growing season. The weed control assessment used a scale ranging from 0% (no weed control) to 100% (complete death of all plants), based on a combined evaluation of weed density reduction, growth inhibition, and foliar injury (Frans et al. 1986).

Crop tolerance to herbicides and application methods was assessed by observing the foliage of the blueberry plants and the newly emerged shoots, referred to as "canes." The evaluation involved assessing leaf necrosis, chlorosis, and distortion across the entire blueberry bush, along with cane stunting, relative to the nontreated control. Injury was assessed using a scale from 0% (no visible injury on the entire blueberry bush) to 100% (complete bush death). All injury ratings were made concurrently with the weed control performance estimates. To determine the impact of treatments on fruit production, blueberries were harvested from the three central bushes within each plot when at least 50% of the berries were ripe (≥80% blue surface). After harvesting, ripe and unripe (green) berries were counted and weighed separately. Blueberry yields were converted to a per-plant estimate before statistical analysis.

Similar to the methodology used for calibrating the banded application boom, the continuous spray volume (V_C) of the WEED-IT™ system was measured before each application by disabling the chlorophyll sensor and allowing the spray solution to flow constantly for 15 s. The effective spray volume (V_E) of the WEED-IT™ system corresponds to the output of the sprayer in targeted spraying mode. For the continuous banded application, the V_E should equal the V_C. The effective spray volumes for both the banded and targeted application systems were determined by measuring the amount of leftover spray solution from each herbicide treatment for each application date. This measurement was used to compute the percentage of field area that received herbicide ($\%_{AT}$) using Eq. [1]:

$$\%_{AT} = \frac{V_E}{V_C} \quad [1]$$

The percentage of sprayed solution saved ($\%_{NS}$) when using the WEED-IT™ system in targeted spraying mode as compared with continuous spraying mode was computed using Eq. [2].

$$\%_{NS} = 1 - \%_{AT} \quad [2]$$

Data analysis. All statistical analyses were conducted using the generalized linear mixed model (GLIMMIX) procedure in SAS software (version 9.4; SAS Institute, Cary, NC, USA). Herbicide treatments, methods of application, and interactions between these two factors were considered fixed effects, whereas year and replication nested within year were designated as random factors in the model. Because of unequal variance, percentage of weed control and crop injury data were converted using the arcsine square root transformation before the analysis of variance and backtransformed for presentation purposes (Grafen and Hails 2002). When main effect interactions were not significant, the data were pooled appropriately and noted below. Mean comparisons for the fixed effects were performed using Tukey's honestly significance test when F values were statistically significant ($P \leq 0.05$).

Results and discussion

Weed control. Common purslane (*Portulaca oleracea* L.), common groundsel (*Senecio vulgaris* L.), and horseweed (*Erigeron canadensis* L.) were the predominant broadleaf weed species in the highbush blueberry trial (Besançon T, personal observation). Because common groundsel and horseweed are winter or early spring annual weeds, ratings were only conducted following the first herbicide application. Common purslane is a summer annual and was a persistent member of the blueberry weed community throughout the growing season; consequently, purslane control rated at both the 2 and 4 WAA and the 2 and 4 WAB timings.

Control of all three species was affected by herbicide and application strategy but not the interaction between the two variables. Control of common groundsel with florpyrauxifen-benzyl applied at 30 or 60 g a.i./ha averaged 30% and 7% at 2 and 4 WAA, respectively (Table 1). Conversely, fluroxypyr at 280 or 560 g a.e./ha controlled common groundsel ≥90% at 2 and 4 WAA, performing as well as, or better than, the 2,4-D choline and glufosinate standards. All herbicides provided 72% to 88% control of horseweed at 2 WAA regardless of rate. Florpyrauxifen-benzyl at 30 or 60 g a.i./ha and fluroxypyr at 560 g a.e./ha provided greater horseweed control at 4 WAA (≥80%) than the glufosinate standard (62%). Common purslane was controlled >90% at 2 and 4 WAA with fluroxypyr at 280 and 560 g a.e./ha compared with ≤75% control with glufosinate and ≤77% with florpyrauxifen-benzyl, regardless of rate. Common purslane control with fluroxypyr at 280 or 560 g a.e./ha surpassed 90% at 2 and 4 WAB, providing equal or greater control than the glufosinate and 2,4-D choline standard treatments. By contrast, control with florpyrauxifen-benzyl following the second application did not exceed 80% at either 30 or 60 g a.i./ha.

Fluroxypyr is an auxin mimic herbicide (Weed Science Society of America group 4) labeled for use in small grains, corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], dry bulb onions (*Allium cepa* L.), and pome fruits (Corteva Agriscience 2008, 2023). Previous research demonstrated that fluroxypyr applied at 110 $g \cdot ha^{-1}$ was effective at providing ≥80% control of glyphosate-resistant horseweed when applied to rosettes that were 5 to 20 cm in diameter (Crose et al. 2020; Mahoney et al. 2016). In the current trial, rosettes were bolting at the time of application; this likely resulted in the lower level of efficacy observed (Besançon T, personal observation). Fluroxypyr is effective at controlling common purslane, as demonstrated by Proctor and Reicher (2013), who reported 100% control at 4 weeks after treatment (WAT) with fluroxypyr applied at 315 g a.e./ha to mature plants. The commercial label recommends fluroxypyr for common purslane control at 120 and 160 $g \cdot ha^{-1}$ when seedlings are less than 10 and 20 cm tall, respectively (Corteva Agriscience 2023). Similar results were observed under the conditions of this trial, further highlighting the value of this chemical for purslane management. Purslane treated with the first application of fluroxypyr were <5 cm in size; conversely, plants that were treated during the second application tended to be larger (up to 15 cm) (Besançon T, personal observation). By contrast, the performance of glufosinate can be significantly affected by purslane size (Proctor and Reicher 2013). At 4 WAT, glufosinate applied at 1120 g a.i./ha achieved 100% control of emerging common purslane but only 9% control of mature plants (Proctor and Reicher 2013). The same study also reported lower efficacy 4 WAT of 2,4-D at 2510 g a.e./ha (66%) compared with glufosinate or fluroxypyr when optimally applied to emerging purslane. Independent of spray system, the results from this study indicate that fluroxypyr in highbush blueberry provided equal or greater control of some troublesome weed species than glufosinate, a standard herbicide for POST applications. Data from the trial have been provided to the IR-4 Project and were used to support additional efficacy and safety studies in support of a possible registration in blueberry (Besançon T, personal communication).

Florpyrauxifen-benzyl is an auxin mimic (Weed Science Society of America group 4) POST herbicide that has demonstrated effective control of various broadleaf weeds (Miller and Norsworthy 2018; Wright et al. 2020), although plant size at the time of treatment can affect performance. For example, Beesinger et al. (2022) indicated that a single application of florpyrauxifen-benzyl at 30 g a.i./ha to 40-cm-tall Palmer amaranth (*Amaranthus palmeri* S.Wats.) provided ≤55% control 4 WAT. In this study, common groundsel and horseweed average heights were 38 and 12 cm, respectively, at the time of application. We hypothesize that the inadequate control of common groundsel in response to florpyrauxifen-benzyl application could be due to the plants being too tall at the time of herbicide application. In the current trial, florpyrauxifen-benzyl provided 80% to 91% control of bolting horseweed rosette; Puntel et al. (2024) reported >80% POST control of Sumatran fleabane [*Conyza sumatrensis* (Retz. E. Walker)] at 24 g a.e./ha under nonflooded conditions in rice (*Oryza sativa* L.).

Averaged over herbicides and rates, banded and WEED-IT™ applications provided equivalent control of common groundsel at 2 WAA (71%); at 4 WAA, common groundsel control was greater

Table 1. Effect of herbicide treatments and application method on common groundsel, horseweed, and common purslane control in highbush blueberry at Hammonton, NJ, USA, in 2021 and 2022.

	Common groundsel (%)		Horseweed (%)		Common purslane (%)			
Treatments	2 WAA	4 WAA	2 WAA	4 WAA	2 WAA	4 WAA	2 WAB	4 WAB
Herbicide (g a.i./ha or g a.e./ha)[i]								
Glufosinate (1680)	78 b	84 a	87	62 c	75 bc	55 bc	92 ab	84 b
2,4-D choline (1600)	91 a	88 a	74	74 bc	90 ab	71 b	90 bc	85 b
Fluroxypyr (280)	90 a	92 a	72	69 bc	94 a	92 a	97 ab	91 ab
Fluroxypyr (560)	94 a	95 a	76	84 ab	92 a	94 a	98 a	97 a
Florpyrauxifen (30)	29 c	6 b	80	82 ab	55 c	37 c	73 d	65 c
Florpyrauxifen (60)	30 c	8 b	88	91 a	77 bc	46 c	80 cd	73 bc
Application method								
Banded	71	67 A	85 A	80 A	83	68	92 A	87
WEED-IT™	72	60 B	74 B	72 B	81	68	86 B	84

[i] 1 $kg \cdot ha^{-1}$ = 0.8921 lb/acre.

The data were pooled across years and means followed by the same letter within in a column are not significantly different based on Tukey's honestly significance test (α = 0.05). WAA = weeks after first application, WAB = weeks after second application.

with the banded application (67%) as compared with the WEED-IT™ system (60%). Greater horseweed control was observed at 2 and 4 WAA following banded applications (85% and 80%) compared with the WEED-IT™ system (74% and 72%). Except for the 2 WAB rating, common purslane control was unaffected by application strategy. At 2 WAB, greater purslane control was observed following a banded treatment (92%) compared with the WEED-IT™ system (86%). Genna et al. (2021) demonstrated that a uniform and continuous glyphosate application reduced total weed cover and density compared with a WEED-IT™ targeted spray. They hypothesized that the targeted sprayer likely provided insufficient spray coverage because of one or more issues: nozzle selection, the sprayer was not activated early enough, or the sprayer did not apply products for a long enough duration. Similar results were observed by Fischer et al. (2020), who reported 24% less surviving of rush skeletonweed (*Chondrilla juncea* L.) plants in a wheat/fallow system, when using the WEED-IT™ system compared with a broadcast herbicide application. Sosnoskie et al. (2023) reported that the performance of the WEED-IT™ system for weed control in grapes was affected by the degree of weed pressure at the time of herbicide application. In 2022, targeted spray applications were equally effective as banded treatments for weed suppression when mean weed cover averaged 5% to 7% across the study site. In 2021, when mean weed cover ranged from 47% to 51%, the WEED-IT™ system provided significantly less early-season control of under-vine weeds compared with the conventional, banded application (Sosnoskie et al. 2023).

Crop injury. Crop injury in the form of foliar necrosis, chlorosis, and leaf deformation was limited to new canes located at the base of the bushes. Herbicide treatment and application method, but not the interaction between the factors, influenced crop injury. Injury on new canes was significantly affected by herbicides at 2 WAA and 2 WAB (Fig. 2). At 2 WAA, the greatest amount of damage was observed with florpyrauxifen-benzyl, although observed injury did not exceed 6%. Injury following glufosinate, 2,4-D choline, and fluroxypyr applications did not exceed 4% at 2 WAA. Greater injury (≥9%) was observed 2 WAB following application of glufosinate, 2,4-D choline, and florpyrauxifen-benzyl compared with fluroxypyr, for which injury did not exceed 5%, regardless of rate.

Foliar injury following banded applications was 3% and 1% at 2 and 4 WAA, respectively, whereas the WEED-IT™ targeted application resulted in 5% and 4% injury (Fig. 3). No significant difference was observed between the application strategies following the second herbicide spray. In addition to causing greater injury to new canes, targeted applications with the WEED-IT™ sprayer also significantly inhibited the development of new blueberry canes (Fig. 4). Stunting of new canes with targeted applications was >8% at 1 WAA but decreased over time to <1% at 4 WAB. In comparison, new cane stunting did not exceed 3% for the banded herbicide application. We hypothesize that the targeted sprayer was detecting the new canes and then activating the spray system. This technology responds to chlorophyll fluorescence, and any green leafy tissue that is within the range of the sensors will be treated the same as unwanted weedy vegetation under the vine. With the banded treatments, the applicator purposely minimized herbicide contact with sensitive foliage by adjusting the boom height. New blueberry canes emerging from the base of the crown are essential to maintain the production potential of highbush blueberry because the productivity of mature canes will gradually diminish (Pritts and Hancock 1985; Retamales et al. 2015). Additionally, necrotic lesions on new canes resulting from repeated use of POST herbicides have been identified as an entry points for *Neofusicoccum* fungi, which are known to cause blueberry stem blight (Tennakoon et al. 2022).

Yield. Blueberry yields were not significantly affected by herbicide, application method, nor their interaction (data not shown). In 2021, the average total yields were 5.1 kg per plant; in 2022, yields dropped to 3.1 kg per plant for blueberries. The observed yield reduction between the two years is likely due to adverse weather conditions that likely affected blueberry fruit set, including subfreezing temperatures in late Apr 2022.

Herbicide use. Across years, the continuous and effective spray volumes of the WEED-IT™ system averaged 746 and 388 L·ha^{-1}, respectively, which were about two to three times higher than the volumes for the uniform banded applications (Table 2). Previous research with the WEED-IT™ system has shown reduction in herbicide use ranging from 50% to 82% (Fischer et al. 2020; Genna et al. 2021). In

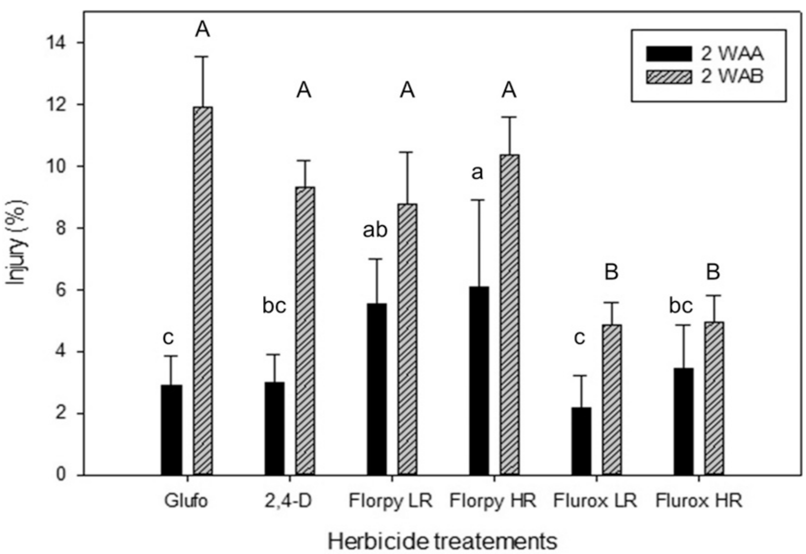

Fig. 2. Effect of herbicide active ingredient on blueberry new cane injury (chlorosis, necrosis, and leaf deformations) at Hammonton, NJ, USA, in 2021 and 2022. Means followed by the same letter are not significantly different at $P \leq 0.05$. Florpy LR = florpyrauxifen at 30 g·ha^{-1}, Florpy HR = florpyrauxifen at 60 g·ha^{-1}, Flurox LR = fluroxypyr at 280 g·ha^{-1}, Flurox HR = fluroxypyr at 560 g·ha^{-1}, Glufo = glufosinate, WAA = weeks after first treatment, WAB = weeks after second treatment.

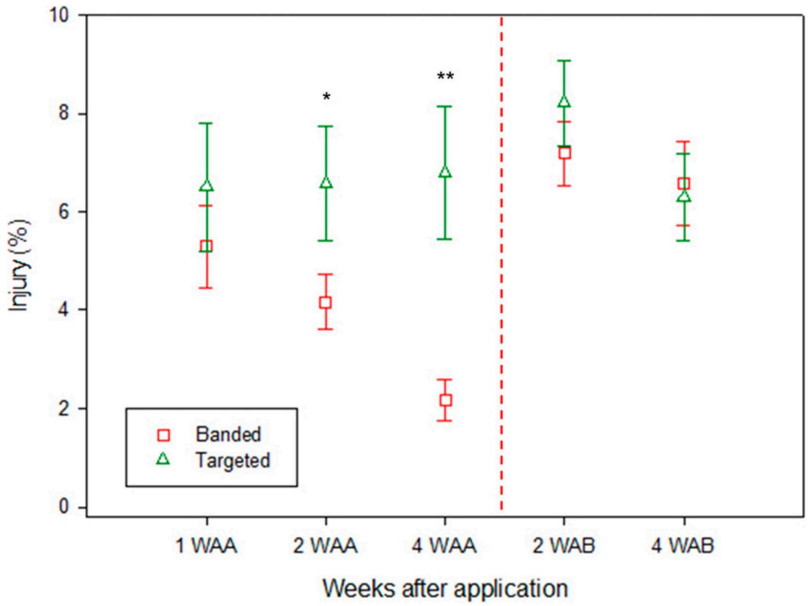

Fig. 3. Effect of herbicide application method on blueberry new cane injury (chlorosis, necrosis, and leaf deformations) at Hammonton, NJ, USA, in 2021 and 2022. Dashed line indicates separation between ratings following the first and second applications. Asterisks above injury means indicate significant difference at $P < 0.01$ (**) and $P < 0.05$ (*). WAA = weeks after first treatment, WAB = weeks after second treatment.

fallow crops, it was suggested that targeted applications using the WEED-IT™ sprayer offer the greatest potential for reducing herbicide use and costs compared with banded applications at 140 L·ha^{-1} when the area treated was less than 30% to 40% (Fischer et al. 2020; Genna et al. 2021). In the present study, a treated area equal to 38% or less was required for achieving an effective WEED-IT™ spray output volume equivalent to the 234 L·ha^{-1} applied with the continuous banded application (Fig. 5). Because no residual herbicides were included in this study, weed cover averaged 58% at the start of the trial in 2022, which limited the value of using the WEED-IT™ systems for reducing herbicide spray volume as compared with a standard banded application. As noted by Genna et al. (2021), the definition of a weed coverage threshold that would economically justify the use of targeted herbicide application also depends on the continuous spray volume of the WEED-IT™ system. Therefore, information should be developed to guide growers on the economic viability of using a targeted system, considering both the system's continuous output and the average percentage of weed cover. For example, Zanin et al. (2022) reported that the use of a WEED-IT™ real-time detection and spray system for weed control ahead of soybean planting reduced the amount of herbicide applied by 76% relative to the predicted spray volumes for conventional treatments. Genna et al. (2021) reported that WEED-IT™ and WeedSeeker™ spray systems used 53% less herbicide for dryland weed control in the Pacific Northwest compared with a continuous spray.

With the use of sensors and precision sprayers, POST herbicide applications can be delivered directly to weeds and not bare soil; this type of targeted approach can minimize waste, cut costs, and lessen the environmental impact of pesticide use. Perennial crops should be well-suited for the use of targeted spray technology because of their relatively tall crop canopies, i.e., the spatial separation of sensitive crop tissue from under-canopy weeds should mitigate the potential risk of crop damage. Sosnoskie et al. (2023) reported greater crop safety in grapes when herbicides were applied using the WEED-IT™ system compared with a continuous banded treatment. A notable difference was observed for 2,4-D choline; although the formulation is less prone to drift and volatility, leaf chlorosis and deformation and vine stunting were still observed under conventional application conditions. Conversely, almost no leaf damage was observed when targeted applications were made (Sosnoskie et al. 2023). Similar levels of crop safety were not achieved in blueberries. Unlike grapes, which did not have any low growing foliage because of manual sucker removal that occurred ahead of herbicide treatments, highbush blueberry produces new canes that emerge from the crown in

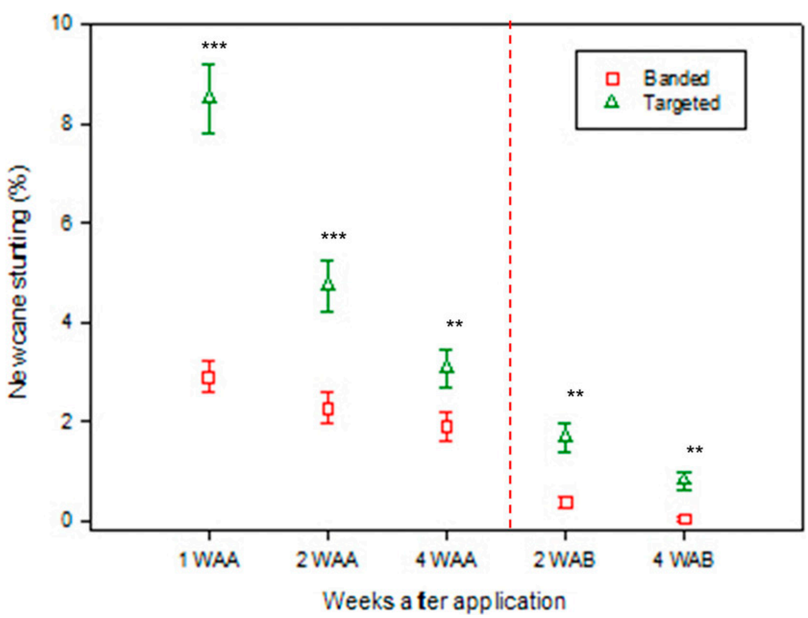

Fig. 4. Effect of herbicide application method on blueberry new cane stunting at Hammonton, NJ, USA, in 2021 and 2022. Dashed line indicates separation between ratings following the first and second applications. Asterisks above injury means indicate significant difference at $P < 0.01$ (**) and $P < 0.001$ (**). WAA = weeks after first treatment, WAB = weeks after second treatment.

Table 2. Area treated and herbicide volume saved by banded application and WEED-IT™ spraying system at Hammonton, NJ, USA, in 2021 and 2022.

Year	Application	Sprayer	Continuous spray volume ($L \cdot ha^{-1}$)	Effective spray volume ($L \cdot ha^{-1}$)[i]	Area treated (%)[ii]	Herbicide volume saved (%)
2021	A	Banded	234	218	93	7
		WEED-IT™	669	303	45	55
	B	Banded	234	229	98	2
		WEED-IT™	669	320	48	52
2022	A	Banded	234	233	100	0
		WEED-IT™	822	457	56	44
	B	Banded	234	228	97	3
		WEED-IT™	822	473	58	42

[i] Effective spray volume is the output of a sprayer in spot-spraying mode.
[ii] Area treated is the effective spray volume divided by the continuous spray volume.

early spring. These shoots were detected by the WEED-IT™ system and subsequently sprayed, resulting in greater crop damage compared with the banded application. These results highlight the need to consider the growth and development of the crop when using targeted spray systems lacking in crop–weed discrimination capabilities.

Both herbicide treatment strategies improved weed control relative to the nontreated check. Targeted applications made with the WEED-IT™ spraying system tended to provide a lower level of weed control than the banded applications. However, the observed results were likely dependent on the amount of weed cover and plant size at the time of treatment; greater densities and/or taller weeds may provide too much shielding and reduce spray coverage. The use of residual products could enhance the performance of the WEED-IT™ system by reducing the emerged weed population, allowing the sprayers to operate more efficiently. Although the continuous and effective spray volumes were greater for the WEED-IT™ spraying system, relative to the banded application, the total treated area and herbicide use were reduced by approximately 50%, while the productivity of blueberry bushes remained unaffected.

Optically guided spray systems are garnering significant interest among fruit growers because of their potential to reduce herbicide use while maintaining effective weed control. In 2020, a survey of 617 perennial crop stakeholders (including growers, consultants, and industry personnel) revealed that 74% had a positive opinion of novel weed management technologies, including targeted sprayers (Sosnoskie LM, unpublished data). These advanced tools enable precise pesticide application, targeting only the areas that require treatment, which can lead to more sustainable production practices. Future trials should focus on evaluating the integration of this technology into comprehensive integrated weed-management programs, particularly those that emphasize strong foundational use of pre-emergence herbicides for optimal results.

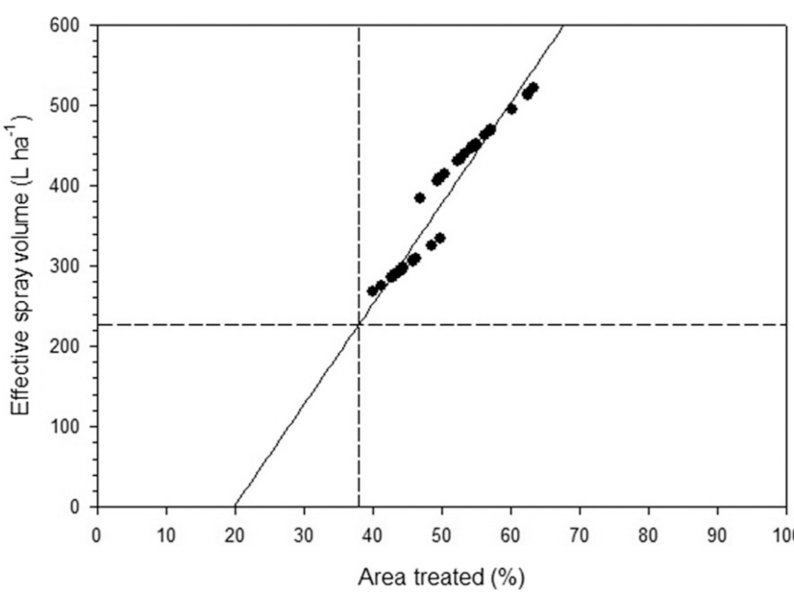

Fig. 5. Relationship between area treated (%) and effective spray volume ($L \cdot ha^{-1}$) for the highbush blueberry trial conducted with the WEED-IT™ sprayer at Hammonton, NJ, USA, in 2021 and 2022. The horizontal dashed line represents the fixed spray output (234 $L \cdot ha^{-1}$) of the banded sprayer.

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