PURDUE UNIVERSITY | Horticulture and Landscape Architecture

Indiana Mint Market Development and Research Council

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Indiana Herbicide Trials

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Indiana Mint Market Development and Research Council – 2023 Herbicide Trials

Location and application information

Experiments were conducted at two different locations from Indiana (Table 1) to evaluate the efficacy of 16 herbicide-based weed management strategies in peppermint. The experiment utilized a randomized complete block design with five replications per treatment at each site. Additionally, non-treated and hand-weeded controls were incorporated into each block, for a total of 18 plots per replication (Table 2). Treatments were applied using a CO_2-pressurized backpack sprayer with a 2 nozzle boom calibrated to deliver 20 gallons per acre (187 L/ha).

Table 1. Information of Indiana locations where experiments were conducted in 2023.

Location	Coordinates	Soil type	Plot size	Application date		Harvest area/plot	Harvesting date	WAT[+]
Gumz Farm (near North Judson)	41°10'39.8"N 86°47'35.3"W	Sandy Loam	3' x 10'	PRE	Aug. 4	11.2 ft^2	Oct. 27	12
				POST	Aug. 16			10
Greg Farm (near Fair Oaks)	41°00'05.7"N 87°15'41.8"W	Loamy sand	3' x 8'	PRE	Aug. 28	2 ft^2	Nov. 15	11
				POST	Sep. 7			10
				Clethodim*	Sep. 12			

*Clethodim was applied due to the high density of grasses in the field. [+]WAT: Weeks After Treatment.

Data collection

Visual crop injury, crop height, and weed counts were recorded every two weeks after treatment (WAT). Injury ratings were on a scale of 0% (no crop injury) to 100% (crop death). In addition, crop biomass was recorded after harvest (Figure 1). Data were analyzed by descriptive and inferential statistics using JMP 16 PRO software.

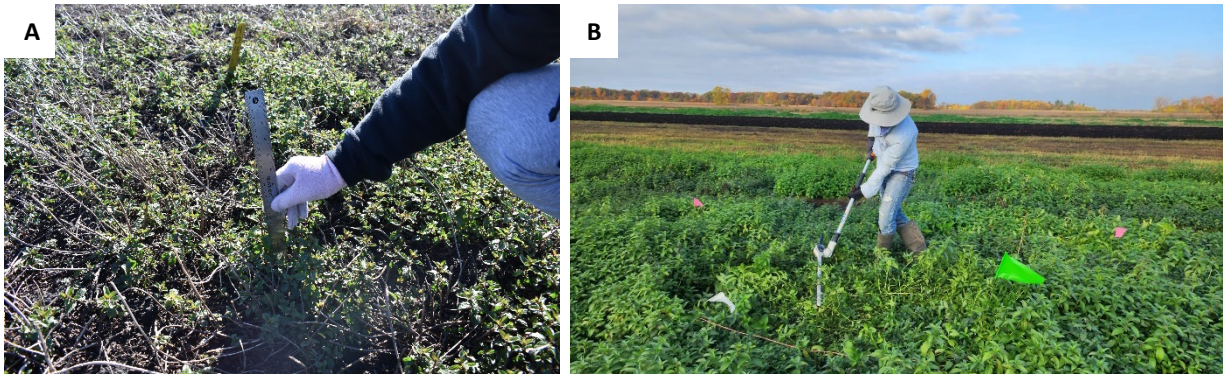

Figure 1. Peppermint plant height measurement(A) and harvesting (B).

Table 2. List of treatments applied to post-harvest peppermint at North Judson and Fair Oaks, IN, 2023.

Plant stage	Treatment*	Rate		Active ingredient
		-- per acre --	-- g ai / ha --	
	Weed-free control	--	--	NA
	Weedy control	--	--	
Pre-emergence	Zidua	1.84 oz	67	pyroxasulfone
	Optogen	3 fl oz	44	bicyclopyrone
	Spartan	4 fl oz	140	sulfentrazone
	Chateau EZ	4 fl oz	121	flumioxazin
	Dual Magnum	1 pt	1068	S-metolachlor
	Fierce EZ	10 fl oz	555	pyroxasulfone + flumioxazin
	Tenacity	3 fl oz	105	mesotrione
Post-emergence	Basagran (4L)	2 pt	1121	bentazon
	Reviton	2 fl oz	50	tiafenacil
	Tough	24 fl oz	1051	pyridate
	Sharpen	2 fl oz	50	saflufenacil
	Anthem Flex	4.5 fl oz	158	pyroxasulfone + carfentrazone
	Tough + Optogen	24 fl oz + 1.5 fl oz	1051 + 22	pyridate + bicyclopyrone
	Tough + Tenacity	24 fl oz + 1.5 fl oz	1051 + 53	pyridate + mesotrione
	Tough + Basagran	24 fl oz + 2 pt	1051 + 1121	pyridate + bentazon
	Aim EC	1 fl oz	18	carfentrazone

ai: active ingredient; ha: hectare; AMS: ammonium sulfate; MSO: methylated seed oil.
*All treatments included 1% MSO and 2% AMS (% v/v).

Results

Crop injury. The herbicides that caused the least injury throughout the experiment were Dual Magnum, Tough+Basagran, Zidua, Tough and Spartan, which produced injury in the range of 2-25 % during the weeks evaluated for both locations. Fierce and Chateau resulted in injury between 1-13 % at North Judson (Table 3), while at Fair Oaks it was between 6-55 % (Table 4). Tenacity and Optogen had the most injury in the first weeks of evaluation, below 20%, but decreasing to 6-8% (Tenacity) and 14-15% (Optogen) at 10-12 WAT at North Judson; however, at Fair Oaks, injury remained between 25-77% and 21-66% for Tenacity and Optogen respectively, throughout the experiment (Figure 2, 3 and 5). Anthem flex resulted in low injury in at North Judson, going from 28% at 1 WAT to 15% at 10-12 WAT; while at Fair Oaks was more injurious, going from 47-53% at 1-2 WAT to 71-53% at 6-8 WAT. Basagran injury was 15-37% during the weeks evaluated for both locations. Aim, injury was <55% at North Judson during all weeks, while at Fair Oaks the injury was between 15-38%, with the exception of 6 WAT. For

Tough + Optogen and Tough + Tenacity, exponential regression models were obtained for North Judson where an injury of ~50% was observed at 1 WAT and reached values >80% from 4 WAT (Figure 4). Injury at Fair Oaks was 34-73% and 23-72% for Tough + Optogen and Tough + Tenacity respectively, with the exception at 6 WAT (>80%). Reviton and Sharpen had the highest injury values among all herbicides evaluated for both locations, 69-99% and 62-96% for Reviton and Sharpen respectively.

Table 3. Peppermint injury following post-harvest herbicide applications at North Judson, IN in 2023.

	Mint injury (WAT)								
Treatment	**0.3**	**1**	**2**	**3**	**4**	**6**	**8**	**10**	**12**
					---- % ----				
Zidua		1 f	7 e	0 c	1 e	5 c	2 c	2 c	3
Optogen		34 bcd	10 e	14 c	19 de	19 bc	28 bc	14 c	15
Spartan		0 f	4 e	3 c	5 de	17 c	13 c	12 c	14
Chateau EZ		6 f	5 e	2 c	4 e	13 c	13 c	7 c	11
Dual Magnum		2 f	3 e	6 c	7 de	17 c	19 bc	11 c	6
Fierce EZ		7 f	1 e	0 c	3 e	6 c	7 c	4 c	1
Tenacity		14 def	10 e	12 c	13 de	17 c	12 c	6 c	8
Basgran	16 bc	31 cd	36 cd	21 bc	33 cd	37 bc	31 bc	27 bc	
Reviton	99 a	88 a	80 a	60 a	69 ab	76 a	81 a	87 a	
Tough	1 d	7 f	16 de	8 c	14 de	26 bc	20 bc	22 bc	
Sharpen	96 a	83 a	83 a	62 a	82 a	87 a	88 a	90 a	
Anthem Flex	4 d	28 cde	48 c	19 bc	23 cde	22 bc	15 c	15 c	
Tough + Optogen	1 d	46 bc	75 ab	74 a	79 a	83 a	87 a	91 a	
Tough + Tenacity	2 d	53 b	77 ab	69 a	79 a	84 a	83 a	88 a	
Tough + Basagran	6 cd	10 ef	17 de	6 c	7 de	21 bc	12 c	21 c	
Aim EC	24 b	46 bc	54 bc	38 b	49 bc	53 ab	54 ab	51 b	

Different letters within a column indicate significant differences ($p \leq 0.05$). WAT: Weeks After Treatment.

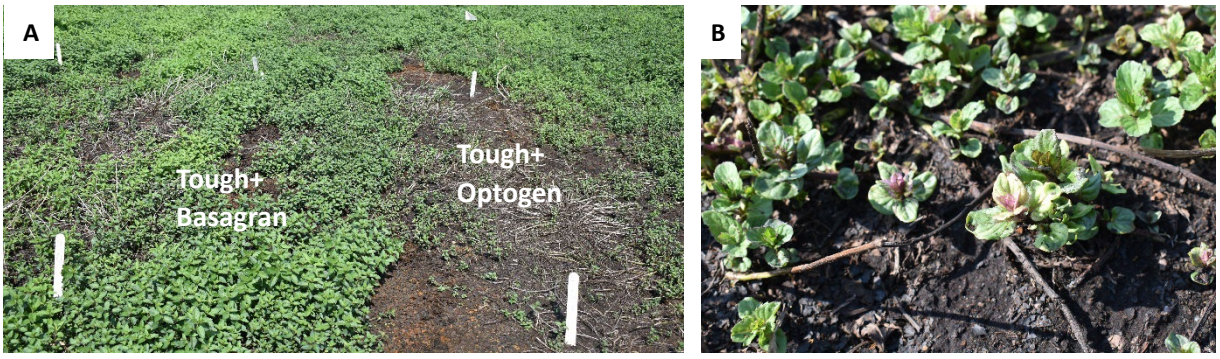

Figure 2. Peppermint plots 4 WAT (A) and Optogen injury 2WAT (B) at North Judson, IN, 2023.

Table 4. Peppermint injury following post-harvest herbicide applications at Fair Oaks, IN in 2023.

Treatment	Mint injury (WAT)						
	1	2	3	4	6	8	10
				---- % ----			
Zidua	10 cd	20 cdef	4 de	8 de	4 c	17 ef	17 cd
Optogen	66 ab	46 cde	30 cd	36 cde	21 c	63 abcd	57 ab
Spartan	14 cd	12 def	4 de	8 de	8 c	21 ef	13 d
Chateau EZ	30 bcd	19 cdef	7 de	12 de	13 c	42 bcdef	41 bc
Dual Magnum	3 d	15 cdef	3 de	4 e	2 c	10 f	16 cd
Fierce EZ	31 bcd	35 cdef	6 de	7 e	10 c	55 abcde	67 a
Tenacity	63 ab	50 bcd	47 bc	49 abcd	25 c	64 abcd	77 a
Basagran	23 cd	15 cdef	20 cde	24 de	33 bc	21 ef	
Reviton	96 a	93 a	91 a	90 a	88 a	84 a	
Tough	11 cd	4 ef	1 e	28 de	31 bc	25 def	
Sharpen	93 a	91 ab	85 a	78 ab	84 a	81 ab	
Anthem Flex	47 bc	53 abcd	47 bc	70 abc	71 a	53 abcde	
Tough + Optogen	34 bcd	44 cdef	63 ab	81 a	86 a	73 ab	
Tough + Tenacity	23 cd	55 abc	68 ab	71 abc	84 a	72 abc	
Tough + Basagran	9 cd	4 f	7 de	31 cde	32 bc	16 ef	
Aim EC	15 cd	18 cdef	30 cd	38 bcde	57 ab	33 cdef	

Different letters within a column indicate significant differences ($p \leq 0.05$). WAT: Weeks After Treatment.

Figure 3. Injury by Tough+Optogen (A), Tough+Tenacity (B), and Tenacity (C) at Fair Oaks, IN, 2023.

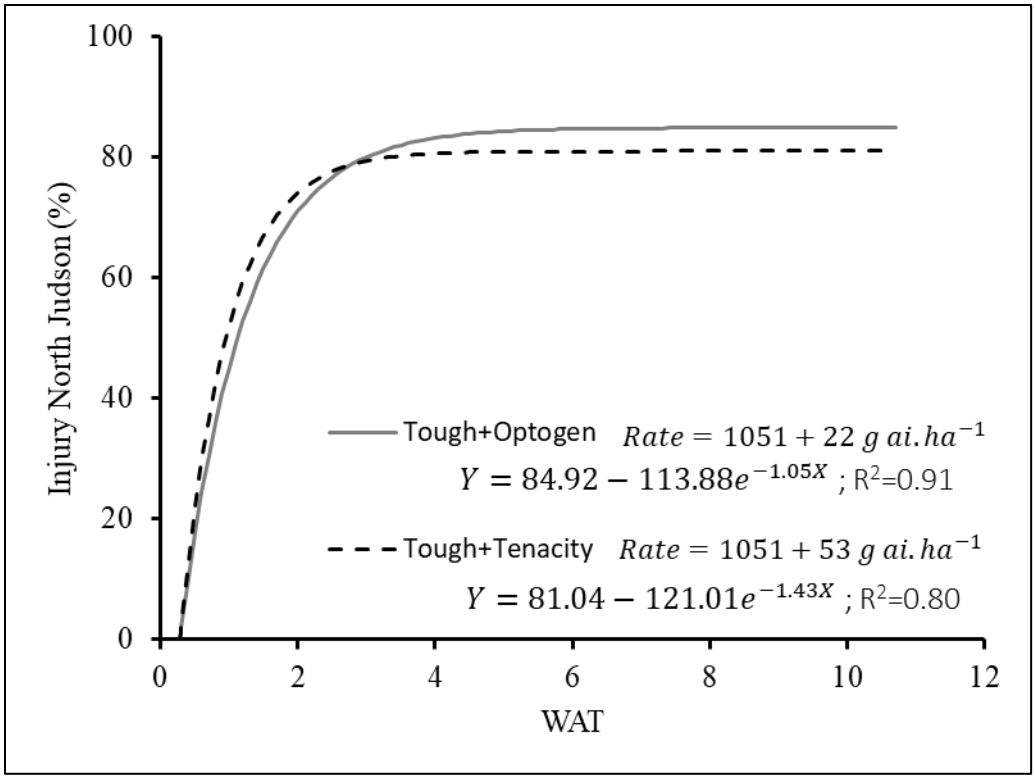

Figure 4. Peppermint injury, 0.3 to 10 WAT with Tough + Optogen and Tough + Tenacity, North Judson IN, 2023.

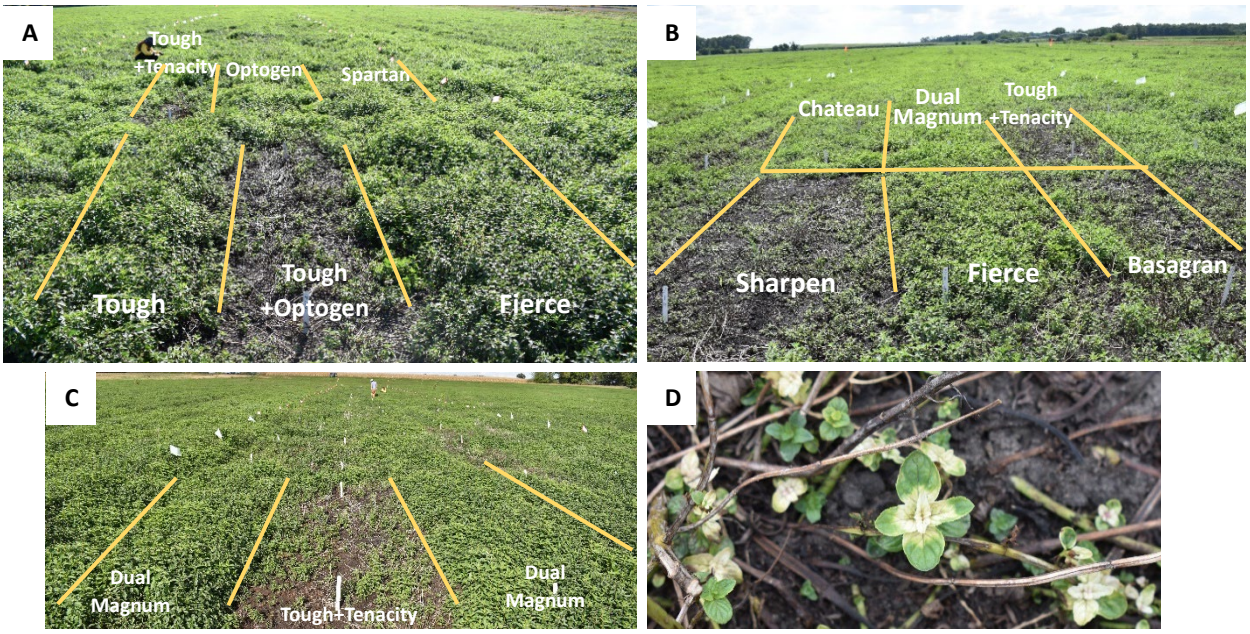

Figure 5. Injury at 8-10 WAT (A), 4-6 WAT (B), 8-10 WAT (C) in North Judson and Optogen at 1 WAT (D) in Fair Oaks, IN, 2023.

Weed count. On North Judson, weed density was very low throughout the field (Table 5). However, by 3 WAT there was the appearance of chickweed (*Stellaria media* L.) and grasses in the plots with Reviton and Tough. Carpetweed (*Mollugo verticillata*) also appeared in these plots in the subsequent weeks (4 weeds/plot). Zidua, Chateau, Tenacity and Optogen contained some grasses by 8 and 10 WAT, ≤ 2 weeds/plot. Basagran, Sharpen, Tough + Tenacity, Tough + Basagran and Aim had ≤ 2 weeds/plot (chickweed and grasses) at 8 WAT. In the case of Fair Oaks, the weeds found during the first 4 WAT were grasses, which had invaded the entire crop. In the pre-emergence herbicides, there were no weeds at 6 WAT (Table 6), while in the post-emergence herbicides 3-7 weeds/plot (broadleaves) were found; however, at 8 and 10 WAT, the field presented a high density of broadleaves (1-7 weeds/plot), with no differences in the number of weeds among the treatments evaluated (Figure 6).

Table 5. Weed count 0.3 to 12 Weeks After Treatment at North Judson, 2023.

		Weed count								
	Treatment	**0.3**	**1**	**2**	**3**	**4**	**6**	**8**	**10**	**12**
						---- per plot ----				
	Weed-free control		0	0	0 b	0 b	1	0 b	0	0
	Weedy control		0	0	0 b	1 ab	1	3 ab	3	0
PRE	Zidua	0	0	0	0 b	0 b	0	1 ab	2	0
	Optogen	0	0	0	0 b	1 ab	1	1 ab	2	0
	Spartan	0	0	0	0 b	0 b	0	0 ab	0	0
	Chateau	0	0	0	0 b	0 b	1	1 ab	1	0
	Dual Magnum	0	0	0	0 b	0 b	0	0 b	0	0
	Fierce EZ	0	0	0	0 b	0 b	0	0 ab	1	0
	Tenacity	0	0	0	0 b	0 b	0	1 ab	1	0
POST	Basgran	0	0	0	0 b	1 ab	0	1 ab	0	
	Reviton	0	0	0	2 a	3 a	1	4 a	0	
	Tough	0	0	1	1 ab	2 ab	2	4 ab	0	
	Sharpen	0	0	0	0 b	0 b	1	1 ab	0	
	Anthem Flex	0	0	0	0 b	0 b	0	0 ab	0	
	Tough + Optogen	0	0	0	0 b	0 b	0	0 ab	0	
	Tough + Tenacity	0	0	0	0 b	0 b	0	1 ab	0	
	Tough + Basagran	0	0	0	0 b	0 b	0	1 ab	0	
	Aim EC	0	0	0	0 b	0 b	0	1 ab	0	

Different letters within a column indicate significant differences ($p \leq 0.05$).

Table 6. Weed count 1 to 10 Weeks After Treatment at Fair Oaks, 2023.

		Weed count (WAT)					
Treatment		**1**	**2**	**4**	**6**	**8**	**10**
		---- per plot ----					
	Weed-free control	1	2	2	4	4	3
	Weedy control	3	3	2	4	7	5
PRE	Zidua	3	3	2	0	5	3
	Optogen	2	1	0	0	7	4
	Spartan	3	5	2	0	4	1
	Chateau	1	2	1	0	1	0
	Dual Magnum	2	1	1	0	5	3
	Fierce EZ	1	1	1	0	1	1
	Tenacity	1	0	0	0	2	2
POST	Basgran	1	3	1	6	5	
	Reviton	1	2	0	5	5	
	Tough	3	2	0	7	5	
	Sharpen	2	2	0	3	3	
	Anthem Flex	3	3	0	5	5	
	Tough + Optogen	4	1	1	7	3	
	Tough + Tenacity	4	2	1	4	3	
	Tough + Basagran	4	3	0	7	4	
	Aim EC	2	1	1	7	4	

Figure 6. Weeds present in the Tough 5 WAT (A), Untreated 2 WAT (B) plots at Fair Oaks and Optogen 10 WAT (C) plot at North Judson, including marestail and grasses.

Peppermint plant height. For the herbicides applied PRE there were no differences in mint plant height with respect to the control at 4, 6, 10 and 12 WAT for North Judson (Table 7), however, by 8 WAT, Optogen had a lower height (15 cm) than the hand-weeded control (28 cm); showing similar results at Fair Oaks, where Optogen had the lowest height (3 cm) at 4 WAT, while at 6 and 8 WAT, Optogen and Tenacity were the shortest (6 cm). In addition, at 10 WAT, there were no differences between PRE treatments (Figure 7). As for the herbicides applied POST, Reviton and Sharpen showed a significant decrease in height for both locations (North Judson: 4-12 cm; Fair Oaks: 2-5 cm) compared to the nontreated (North Judson: 14-33 cm; Fair Oaks: 9-12 cm). Tough + Optogen and Tough + Tenacity reduced mint height (9-10 and 4-8 cm for North Judson and Fair Oaks, respectively) at 8 and 10 WAT. In the other treatments there was a gradual recovery in mint plants, nevertheless, Aim (17 cm in GUMZ) and Anthem Flex (6 cm in Fair Oaks) significantly decreased from the weed-free control, at 10 and 8 WAT respectively (Figure 8).

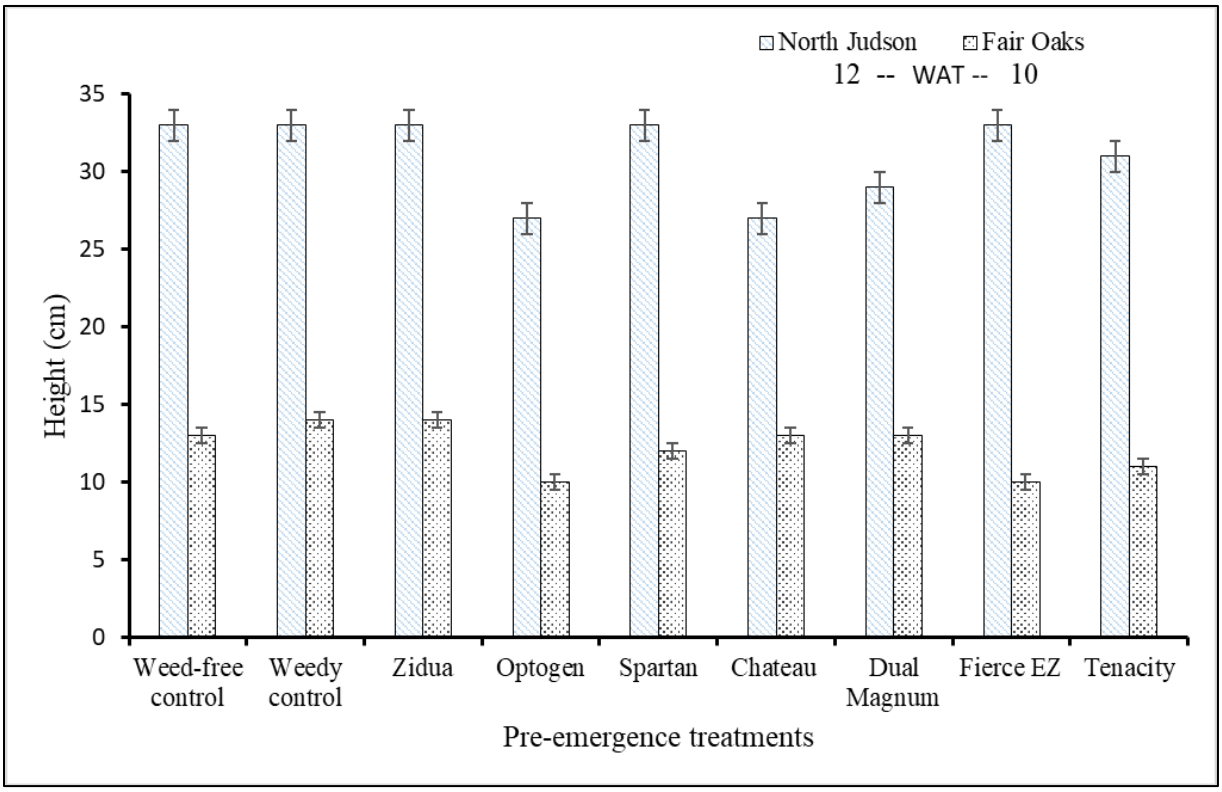

Figure 7. Peppermint plant height for pre-emergence treatments at North Judson and Fair Oaks, IN, 2023. Bars with standard error are the means of five plots (five plants per plot).

Table 7. Peppermint plant height following post-harvest herbicide applications at North Judson and Fair Oaks, IN, 2023.

		Mint Plant Height (WAT)									
		North Judson						Fair Oaks			
Treatment	**Plant stage**	**3**	**4**	**6**	**8**	**10**	**12**	**4**	**6**	**8**	**10**
			-- average 5 plants (cm) --					-- average 5 plants (cm) --			
Weed-free control	--		10	16	28 a	33	33	7 ab	9 ab	11 a	13
Weedy control			8	14	24 ab	33	33	9 a	9 ab	12 a	14
Zidua	PRE	--	9	17	23 ab	28	33	6 abc	10 ab	10 ab	14
Optogen			7	13	15 b	23	27	3 c	6 b	6 b	10
Spartan			8	14	19 ab	22	33	6 abc	9 ab	10 ab	12
Chateau			8	12	19 ab	25	27	5 abc	8 ab	8 ab	13
Dual Magnum			9	13	20 ab	25	29	6 abc	11 a	11 a	13
Fierce EZ			9	12	21 ab	28	33	5 abc	8 ab	8 ab	10
Tenacity			7	11	18 ab	26	31	5 bc	6 b	7 b	11
Weed-free control	POST	14 a	15 a	28 a	33 a	33 a	--	9 ab	12 ab	11 ab	--
Weedy control		10 ab	15 a	24 ab	33 a	33 a		9 ab	14 a	13 a	
Basgran		8 bc	9 ab	13 cde	20 bc	25 ab		6 abcd	7 cd	9 abc	
Reviton		4 c	5 b	7 de	10 cde	12c		2 e	3 e	5 c	
Tough		9 abc	12 ab	17 bcd	20 bcd	25 ab		9 a	10 bc	10 ab	
Sharpen		4 c	4 b	6 e	8 e	9 c		3 de	3 e	5 c	
Anthem Flex		9 abc	12 ab	13 cde	22 ab	24 ab		3 de	4 de	6 bc	
Tough + Optogen		7 bc	6 ab	8 cde	9 de	9 c	--	3 cde	4 de	5 c	--
Tough + Tenacity		5 bc	7 ab	6 e	9 e	10 c		4 cde	6 de	8 abc	
Tough + Basagran		10 abc	15 a	19 abc	26 ab	29 ab		7 abc	8 cd	9 abc	
Aim EC		5 bc	7 ab	10 cde	11 cde	17 bc		5 bcde	6 de	8 abc	

Different letters within a column indicate significant differences ($p \leq 0.05$).

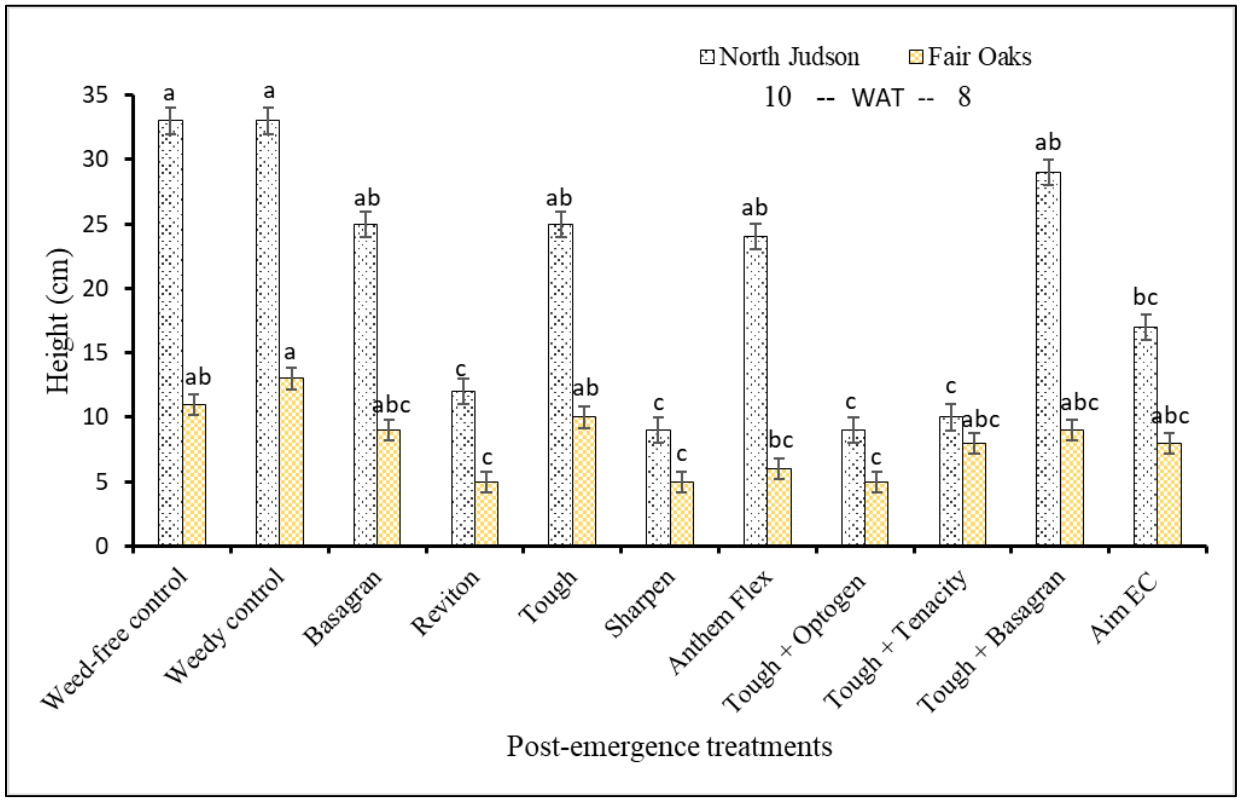

Figure 8. Peppermint plant height for post-emergence treatments at North Judson and Fair Oaks, IN, 2023. Bars with standard error are the means of five plots (five plants per plot). Different letters represent significant differences among means within a location based on Tukey's HSD p≤0.05.

Peppermint biomass. The treatments that did not significantly reduce the biomass in the mint crop with respect to the biomass of the controls (214 g/m^2 for North Judson and 89 g/m^2 for Fair Oaks) were Chateau, Fierce, Zidua, Dual Magnum, Spartan, Tough + Basagran, Tough, Optogen and Basagran (Figure 9). Although Tenacity and Anthem Flex had similar biomass (205 and 172 g/m^2) to the nontreated control at North Judson, they had significantly lower biomass (37 and 34 g/m^2) at Fair Oaks. Aim did not differ from the control at Fair Oaks (59 g/m^2) but was lower at North Judson (104 g/m^2). Reviton, Tough + Optogen, Tough + Tenacity, and Sharpen were the treatments with the lowest biomass at harvest (<70 g/m^2 for North Judson and ≤23 g/m^2 for Fair Oaks).

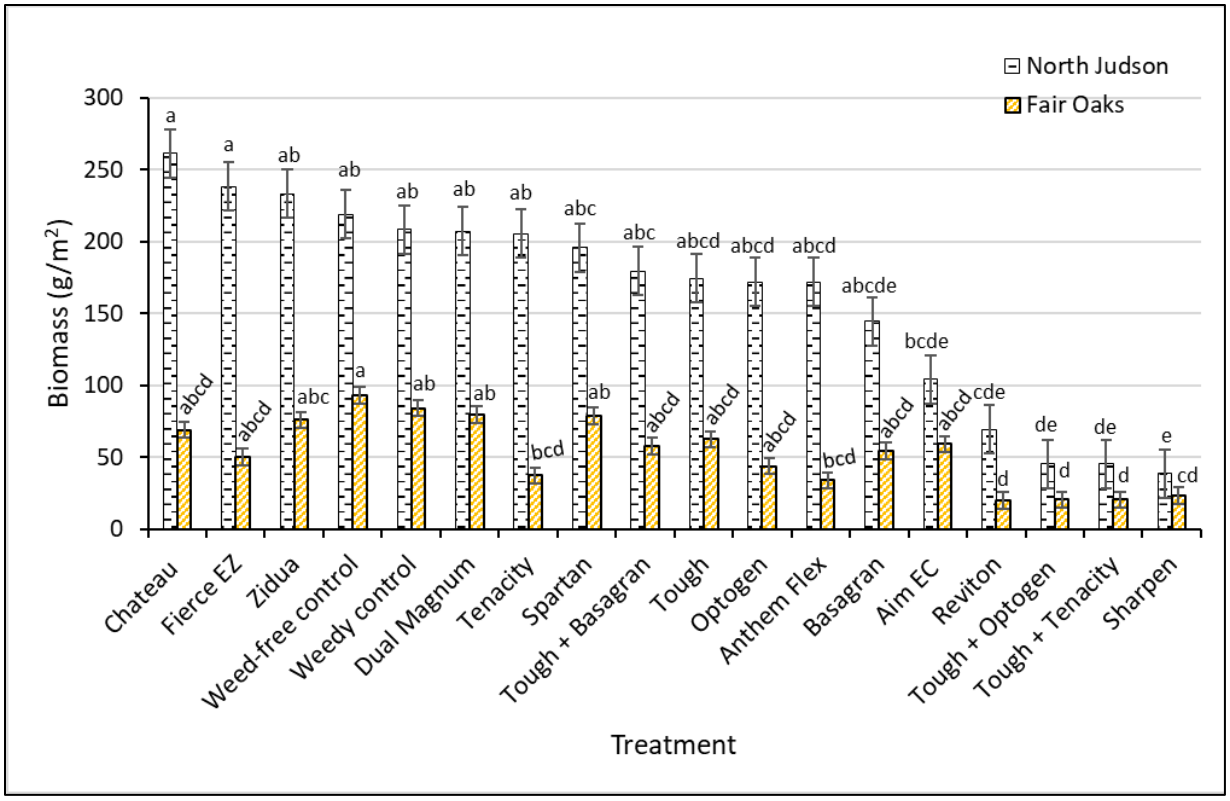

Figure 9. Peppermint biomass (>10 WAT) at North Judson and Fair Oaks, IN, 2023. Bars with standard error are the means of five plots. Different letters represent significant differences among means within a location based on Tukey's HSD p≤0.05.

Conclusions

The results showed clear differences among the various treatments. Several pre-emergence herbicides including Zidua, Spartan, Chateau, Dual Magnum and Fierce, as well as some post-emergence herbicides (Tough + Basagran, Tough) performed very well, causing little injury (<25%) and providing effective post-harvest weed control (Figure 10). These resulted in excellent crop growth and harvestable biomass, similar to the weed-free control. On the other hand, post-emergence herbicides like, Reviton, Sharpen and combinations such as Tough + Optogen and Tough + Tenacity caused significant injury (>50%) and reductions in height and biomass. Intermediate results were seen with Basagran, Tenacity, Anthem Flex, Optogen and Aim EC which injured crops initially but allowed for some recovery. In addition, it was observed low weed pressure at North Judson and higher broadleaf weed pressure was observed starting at 6 WAT at Fair Oaks.

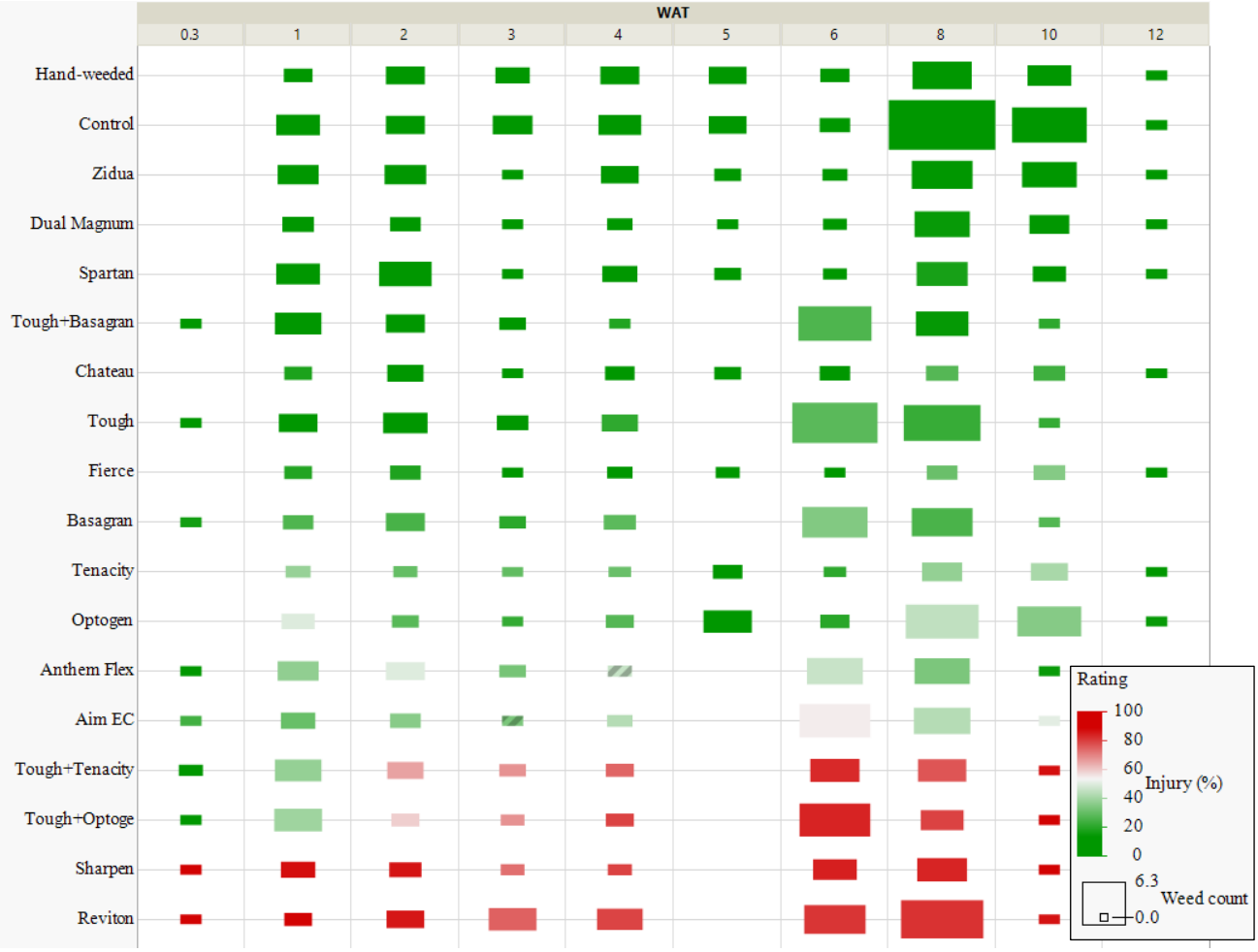

Figure 10. Peppermint injury by colors and weed count by frame size following post-harvest herbicide applications pooled across locations (North Judson and Fair Oaks, IN) in 2023.

Next steps

Submit data to IR-4 database, consult with Indiana Mint Market Development & Research Program and Mint Industry Research Council (MIRC) to pursue potential registrations of Chateau EZ, Fierce, Zidua, Dual Magnum and Spartan [24(c)]. Moreover, according to this study, combinations of Tough with group 27 herbicides such as Tenacity and Optogen should be avoided. Group 14 herbicides including Aim, Reviton, and Sharpen are not safely applied in post-harvest peppermint.