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Simulated dormant peppermint (*Mentha* × *piperita*) response to mesotrione: a greenhouse study

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Research Article

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Mesotrione; peppermint, *Mentha* × *piperita* L. (pro sp.) *aquatica* × *spicata* 'Redefined Murray Mitcham'

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Abstract

A dose-response trial was conducted in two experimental runs at the Purdue University Horticulture Greenhouses, West Lafayette, IN, in 2021/2022 to determine the effect of mesotrione rate on simulated dormant 'Redefined Murray Mitcham' peppermint. Peppermint was established in 20-cm-diam polyethylene pots, it was then harvested, and pots were placed in a cooler (4 C) for 1 mo. Potted peppermint plants were removed from cold storage and treated with one of five mesotrione rates: 0 (nontreated control), 53, 105, 210, or 420 g ai ha^{-1}. As mesotrione rate increased from 53 to 420 g ai ha^{-1}, predicted peppermint injury increased from 35% to 80% at 2 wk after treatment (WAT), 36% to 95% at 4 WAT, 9% to 82% at 6 WAT, and 8% to 90% at 8 WAT; and peppermint height decreased from 74% to 42% of the nontreated control (7 cm) 2 WAT, 74% to 17% of the nontreated control (20 cm) 4 WAT, 81% to 15% of the nontreated control (28 cm) 6 WAT, and 88% to 19% of the nontreated control (37 cm) 8 WAT. Mesotrione rates from 53 to 420 g ai ha^{-1} reduced peppermint dry weight from 40% to 99%, respectively. Results from this experiment showed that mesotrione applied even at half of the recommended field use rate for corn (53 g ai ha^{-1}) was not safe for peppermint due to a reduction in aboveground biomass.

Introduction

Peppermint is a globally grown, perennial herb of the *Laminaceae* family. The crop is primarily cultivated for the leaves, which are dried and distilled for oil production and used for pharmaceutical, food, and cosmetic industries. In the Midwest, Indiana is the major producer of peppermint for oil, whereas Idaho, Oregon, and Washington are the main producers in the Pacific Northwest (USDA-NASS 2021). In 2021, 17,810 ha of peppermint were harvested across the United States with Indiana contributing ~13% (2,230 ha). The total production of peppermint oil nationally was 1.88 million kg and had a total value of US$87.7 million, of which Indiana attributed 118,000 kg (US$6.5 million; USDA-NASS 2022).

Peppermint is grown as a short-term perennial in rotation with field crops in the Midwest. Fields are established by transplanting 7- to 10-cm rhizome pieces into rows 76 to 91 cm apart (Weller et al. 2000). This first-year peppermint, known as "baby mint" or "row mint," may be harvested if conditions favor sufficient crop growth. The aboveground biomass, referred to as "mint hay," is harvested once or twice during summer and is then steam-distilled to extract mint oil. Most peppermint in Indiana is harvested once a year; however, fields in their final production year will often be harvested twice. After the last harvest, peppermint that is to continue for another production cycle is left to grow until winter, when it enters the dormant period. After the onset of dormancy and if soil conditions are favorable, some producers will disc peppermint fields to control winter annual weeds that have emerged and bury peppermint stolons as a means of winter protection. In the early spring, when the soil temperature starts to increase, the crop breaks dormancy. At this time, the growing mint must compete with winter annual weeds and newly emerging summer annual and perennial species.

Peppermint production and steam distillation are capital-intensive because of the management techniques and specialized equipment they require. Poor quality and low yield of peppermint can be a serious challenge for growers (Rushman 1999). Perennial weeds like quackgrass [*Elymus repens* (L.) Gould], Canada thistle [*Cirsium arvense* (L.) Scop.], and field bindweed (*Convolvulus arvensis* L.) can be excellent competitors with mint, and can hinder mint plant growth and yield (Weller et al. 2000). Weeds reduce peppermint oil yield by reducing nitrogen and water availability for the plant (Zheljazkov et al. 1996). In addition to crop yield loss, many weeds can also affect the flavor of the mint oil because of noxious compounds they produce during the steam distillation process, resulting in low-quality mint oil (C. Matthys, personal communication).

In the United States, mint growers rely on the use of herbicides for in-season weed control because mechanical weed control is impractical due to the spread of mint roots and rhizomes after the first year. Although discing can occur during dormancy, mechanical weed control during active crop growth will result in unacceptable damage to peppermint roots and rhizomes. Herbicides are usually applied in the late winter or early spring prior to mint breaking dormancy and often include a combination of a preemergence herbicide and a postemergence herbicide to control emerged weeds and to provide residual, early season weed control. Ten herbicidal active ingredients are registered for use in Indiana peppermint crops prior to breaking dormancy, and each has limitations (Midwest Vegetable Production Guide 2023). Group 14 herbicides (as categorized by the Weed Science Society of America [WSSA]) include carfentrazone, flumioxazin, oxyfluorfen, and sulfentrazone. Carfentrazone alone does not provide effective weed control of problematic winter annual weeds common to peppermint, including henbit (*Lamium amplexicaule* L.), common chickweed [*Stellaria media* (L.) Vill.], and marestail (*Erigeron canadensis* L.) (Anonymous 2016). Oxyfluorfen can be applied to peppermint only on muck soils; however, much of Indiana peppermint is produced on mineral soils. Spring applications of sulfentrazone must follow a spring cultivation; however, much of Indiana peppermint is not tilled during dormancy or it is tilled in the late fall to early winter. Additionally, WSSA Group 3 (pendimethalin and trifluralin), Group 5 (terbacil), Group 13 (clomazone), Group 15 (napropamide), and Group 22 (paraquat) herbicides are available in Indiana for use with mint crops.

Across all herbicide application timing in peppermint, growers rely heavily on WSSA Group 5 and Group 6 photosystem II inhibitors, including bentazon, pyridate, and terbacil. Five weed species have documented resistance to herbicides that inhibit photosystem II in mint: prostrate pigweed (*Amaranthus blitoides* S. Wats.), Powell amaranth (*A. powellii* S. Wats.), redroot pigweed (*A. retroflexus* L.), common lambsquarters (*Chenopodium album* L.), and common groundsel (*Senecio vulgaris* L.) (Heap 2022). The registration and use of herbicides with different modes of action would be beneficial to mint growers so as to increase the spectrum of weeds that can be controlled and to slow the evolution of herbicide resistance.

Currently, no Group 27 herbicides (4-hydroxyphenyl pyruvate dioxygenase [HPPD] inhibitors) are registered for use in mint. In plants, HPPD is a component of the biosynthetic pathway that converts tyrosine to plastoquinone and α-tocopherol (Mayer et al. 1990). Plastoquinone is a critical cofactor for phytoene desaturase, a component of the carotenoid biosynthetic pathway (Norris et al. 1995). Therefore, inhibiting HPPD in plants leads to depletion of plastoquinone levels resulting in reduction of carotenoids, thus causing bleaching symptoms in plants (Mayer et al. 1990). Mesotrione is a selective, systemic herbicide that can be used preemergence and postemergence to control many broadleaf weeds in crops of corn (*Zea mays* L.) and sugarcane (*Saccharum officinarum* L.) (Anonymous 2017). Mesotrione is effective in controlling most of the broadleaf weeds commonly found in Indiana mint fields including pigweeds (*Amaranthus* spp.), carpetweed (*Mollugo verticillata* L.), common chickweed, common lambsquarters, and velvetleaf (*Abutilon theophrasti* Medik.) (Anonymous 2017). Many of the state's peppermint producers already use mesotrione in their corn weed management programs, and preliminary data presented by Gumz and Weller (2005) suggest that when applied to nonemerged, dormant peppermint, crop injury is minimal and transient. Therefore, the objective of this study was to evaluate the effect of mesotrione rates on simulated dormant peppermint plant growth.

Materials and Methods

Greenhouse trials were conducted in two experimental runs at the Purdue University Horticulture Greenhouses, West Lafayette, IN (40.4208°N, 86.9147°W), in 2021 (23 C, 54% relative humidity, 16-h photoperiod). Peppermint propagation and establishment procedures followed methods outlined by Meyers et al. (2022). The experimental unit consisted of a 20-cm-diam polyethylene pot. A coffee filter was placed into the bottom of each pot to help retain the substrate. Then pots were filled with a substrate consisting of a 1:1 (vol/vol) mix of potting soil (Metro-Mix 510; Sungro Horticulture, Agawam, MA) and sand with a resulting substrate pH 7.2 and 5.8% organic matter. On August 30 (Experimental Run 1) and 31 (Experimental Run 2), 2021, 'Redefined Murray Mitchem' peppermint shoot tip cuttings of 10 to 15 cm were collected from stock plants. Stock plants grown at the Purdue University Horticulture Greenhouses were originally from a commercial production field in Rensselaer, IN (40.9988°N, 87.2378°W). Immediately after cutting, leaves were stripped from the proximal half of each cutting, then four cuttings were planted in each pot with three nodes and corresponding leaves above the substrate surface. Overhead irrigation with clear water (no fertilizer) was provided as needed to maintain even substrate moisture. Once plants began to grow, irrigation events alternated between fertilizer water and clear water. At 8 wk after planting (WAP), peppermint stolons and rhizomes were encircling the inside of the pots and shoot tissues had established a uniform canopy across the substrate surface. At this time, peppermint aboveground biomass was harvested at the substrate surface and pots containing roots, rhizomes, and stolons directly atop the substrate surface were placed into a cooler (4 C, 12-h photoperiod, 35 µmol m^{-2} s^{-1}) for a period of 1 mo to simulate winter dormancy.

Pots for Experimental Runs 1 and 2 were removed from cold storage on November 22 and 23, 2021, respectively, and treated the same day. Mesotrione (Argos®; Helm Agro, Inc., Tampa, FL) was applied at five rates (0, the nontreated control; 53; 105; 210; or 420 g ai ha^{-1}) using a compressed-air spray booth (Generation III track sprayer; DeVries Manufacturing, Inc., Hollandale, MN) fitted with a single TeeJet® 8002 EVS nozzle tip (Spraying Systems Co., Wheaton, IL) and calibrated to deliver 187 L ha^{-1} at 207 kPa. All pots were returned to the greenhouse after herbicide application and were not irrigated for at least 24 h. Experimental runs were separated by benches in the greenhouse. Throughout the remainder of the study, pots were watered as previously described to maintain even substrate moisture.

Data collection included visible crop injury ratings on a scale of 0% (no injury) to 100% (crop death); height (centimeters) of five shoots per pot; and aboveground biomass recorded as dry weight (grams per pot) after oven-drying for 24 h at 60 C. Crop injury and height data were collected 2, 4, 6, and 8 wk after treatment (WAT), and the aboveground biomass data were collected 8 WAT. The experimental design was a randomized complete block with four

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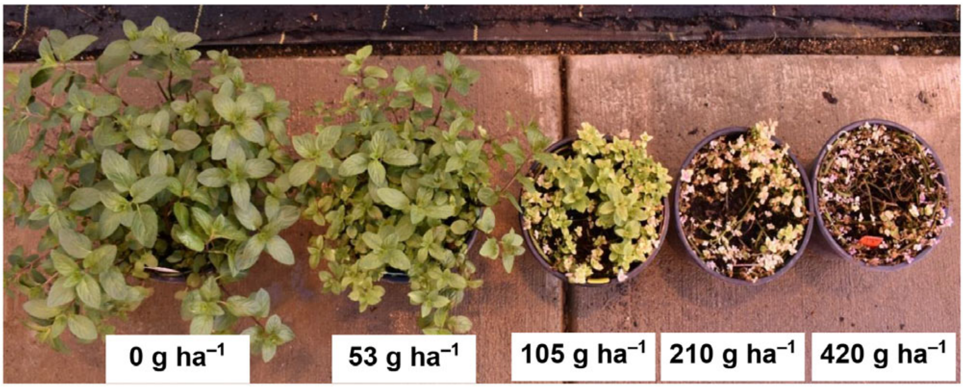

Figure 1. 'Redefined Murray Mitcham' peppermint herbicide symptomology 4 wk after treatment with mesotrione at the Purdue University Horticulture Greenhouses, West Lafayette, IN, in 2021.

replications per experimental run. Both height and dry weight data were converted to a percent of the nontreated control using Equation 1:

$$\text{Percent of control} = \frac{B}{M} \times 100 \qquad [1]$$

where M is the average of the nontreated control variable value pooled across the four repetitions within each experimental run, and B is the variable value of each data point for each experimental run.

Data were subjected to statistical analysis using R software (RStudio®; PBC, Boston, MA). Primary analysis of the data was performed for each experimental run with a linear model and subjected to ANOVA to determine whether the models were statistically significant for each experimental run. If models were significant, data were combined across both experimental runs to check whether the normality of the data was affected and to determine whether statistically significant interactions ($P \leq 0.05$) existed between the explanatory variables (mesotrione rate and experimental run) for each response variable. Response variables were visible peppermint injury at 2, 4, 6, and 8 WAT; height as a percent of the nontreated control at 2, 4, 6, and 8 WAT; and dry weight as a percent of the nontreated control at 8 WAT. Data from the nontreated control were excluded from the visible mint injury data analysis due to zero variance. Models for significant response variables were then subjected to nonlinear regression analyses using the DRC package in R software and fit a three-parameter log-logistic model (Knezevic et al. 2007) using Equation 2:

$$Y = \frac{d}{1 + \text{Exp}\left[b(\log x - \log e)\right]} \qquad [2]$$

where d is the upper limit, b is the relative slope around e, e is the inflection point, and x is the mesotrione rate in grams of active ingredient per hectare (g ai ha^{-1}), or a four-parameter log-logistic model (Knezevic et al. 2007) using Equation 3:

$$Y = c + \frac{d - c}{1 + \text{Exp}\left[b(\log x - \log e)\right]} \qquad [3]$$

where c is the lower limit, d is the upper limit, b is the relative slope around e, e is the inflection point, and x is the mesotrione rate in g ai ha^{-1}. Nonlinear model fit was analyzed with a lack-of-fit test, where a value of $P > 0.05$ indicates that the nonlinear model provides an adequate description of the data (Knezevic et al. 2007).

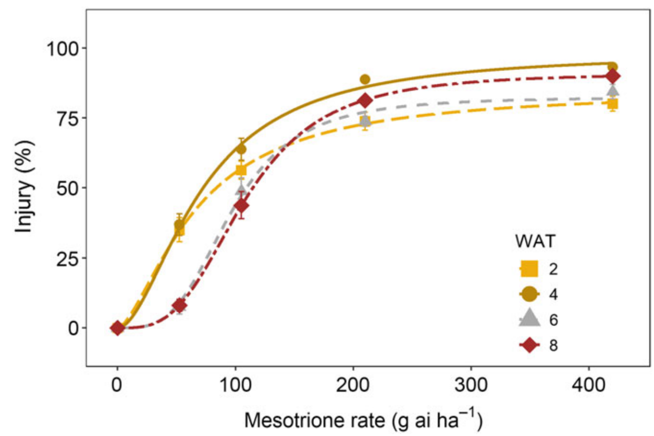

Figure 2. Effect of mesotrione rate on 'Redefined Murray Mitchem' peppermint injury at 2, 4, 6, and 8 wk after treatment (WAT) at the Purdue University Horticulture Greenhouses, West Lafayette, IN, in 2021/2022. Points represent observed mean data, and lines represent the predicted peppermint injury based on a three-parameter log-logistic model (Equation 2): Y = {d/ (1 + *Exp* [b (log x – log e)]}. Parameters for 2 WAT: b = −1.56, d = 85.03, and e = 66.63, with a lack-of-fit P = 0.915; 4 WAT: b = −1.79, d = 98.46, and e = 71.27, with a lack-of-fit P = 0.34; 6 WAT: b = −3.42, d = 82.42, and e = 96.26, with a lack-of-fit P = 0.26; and 8 WAT: b = −3.2, d = 91.04, and e = 107.75, with a lack-of-fit P = 0.99.

Results and Discussion

Peppermint injury, plant height, and dry weight data were pooled across experimental runs due to no significant mesotrione rate-by-experimental run interaction. Visible injury included bleaching, stunting, chlorosis, reduced leaf size, and necrosis (Figure 1). Injury data were fit to a three-parameter log-logistic model (Equation 2). As mesotrione rate increased from 53 to 420 g ai ha^{-1}, predicted peppermint injury increased from 35% to 80% at 2 WAT, 36% to 95% at 4 WAT, 9% to 82% at 6 WAT, and 8% to 90% at 8 WAT (Figure 2). Injuries observed during the 6 and 8 WAT times consisted primarily of stunting, bleaching, and some necrosis of plants treated with the highest mesotrione rate. By 6 WAT, peppermint that received the 53 g ai ha^{-1} rate of mesotrione had visually recovered. The color and physical appearance of shoots were similar to plants that had received the control treatments,

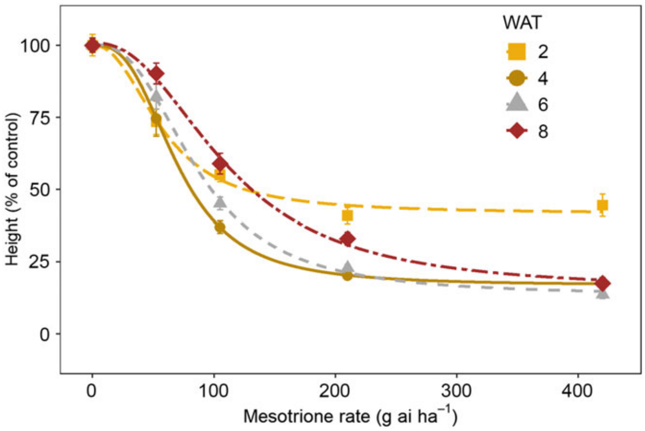

Figure 3. Effect of mesotrione rate on 'Redefined Murray Mitcham' peppermint height as a percent of the nontreated control at 2, 4, 6, and 8 wk after treatment (WAT) at the Purdue Horticulture Greenhouses, West Lafayette, IN, in 2021/2022. Points represent observed mean data, and lines represent the predicted peppermint height as a percent of the nontreated control based on a four-parameter log-logistic model (Equation 3): Y = c +{d – c/ (1 + *Exp* [b (log x – log e)]}. Parameters for 2 WAT: b = 2.30, c = 41.49, d = 99.91, and e = 57.83, with a lack-of-fit P = 0.20; 4 WAT: b = 2.84, c =16.88, d = 99.99, and e = 70.12, with a lack-of-fit P = 0.94; 6 WAT: b = 2.59, c = 13.36, d = 100.25, and e = 86.46, with a lack-of-fit P = 0.39; and 8 WAT: b = 2.35, c = 15.05, d = 100.85, and e = 111.53, with a lack-of-fit P = 0.19. Average shoot heights of the nontreated control pooled across experimental runs were 7 cm at 2 WAT, 20 cm at 4 WAT, 28 cm at 6 WAT, and 37 cm at 8 WAT.

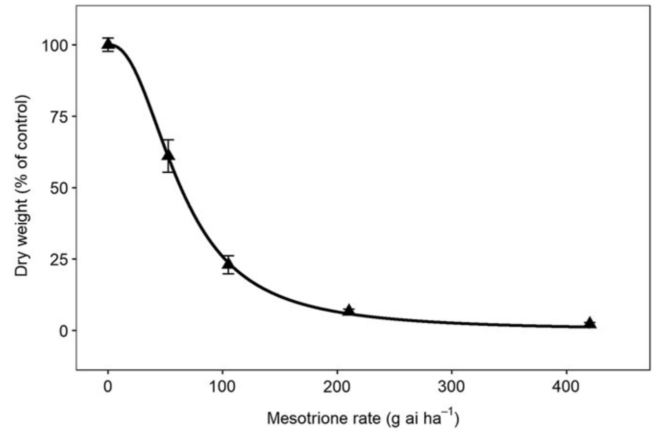

Figure 4. Effect of mesotrione rate on 'Redefined Murray Mitcham' peppermint aboveground dry biomass as a percent of the nontreated control at 8 wk after treatment at the Purdue University Horticulture Greenhouses, West Lafayette, IN, in 2022. Points represent observed mean data, and the line represents the predicted peppermint aboveground dry biomass as a percent of the nontreated control based on a three-parameter log-logistic model (Equation 2): Y = {d/ (1 + *Exp* [b (log x – log e)]}. Parameters: b = 2.32, d = 100.07, e = 63.43, and lack-of-fit P = 0.89. Average aboveground dry biomass of the nontreated control pooled across experimental runs was 42 g pot^{-1}.

although they appeared stunted. However, injury from all other mesotrione rates was persistent (≥44%) through 8 WAT.

Peppermint plant height data as a percent of the nontreated control fit a four-parameter log-logistic model (Equation 3). As the mesotrione rate increased from 53 to 420 g ai ha^{-1}, predicted peppermint height decreased from 74% to 42% of the nontreated control (7 cm) at 2 WAT, 74% to 17% of the nontreated control (20 cm) at 4 WAT, 81% to 15% of the nontreated control (28 cm) at 6 WAT, and 88% to 19% of the nontreated control (37 cm) at 8 WAT (Figure 3).

Peppermint dry weight data as a percent of the nontreated control fit a three-parameter log-logistic model (Equation 2). As the mesotrione rate increased from 53 to 420 g ai ha^{-1}, peppermint dry weight decreased from 60% to 1% of the nontreated control (42 g pot^{-1}; Figure 4). Even the lowest mesotrione rate used (53 g ai ha^{-1}) in this study resulted in significantly reduced peppermint aboveground biomass.

These results are similar to those reported by Gumz and Weller (2005), who applied mesotrione at 70, 105, and 210 g ai ha^{-1} to dormant, emerged spearmint (*Mentha spicata* L.) and reported 10%, 25%, and 75% injury, respectively, 28 d after treatment (DAT). However, those authors reported no injury to dormant, nonemerged peppermint receiving the same rates of mesotrione. Furthermore, Gumz and Weller (2005) reported that symptoms were transient, and that by 74 DAT spearmint had recovered, and neither peppermint nor spearmint yields were reduced by mesotrione compared to a standard control of 900 g ai ha^{-1} terbacil. Because we terminated our study at 56 DAT, we cannot speculate whether plants treated with mesotrione rates of 105 to 420 g ha^{-1} may have recovered with additional time. However, given the severity and persistence of injury following mesotrione treatment, we determined that injury was not transient and that any recovery beyond 8 WAT would be unacceptable to peppermint producers.

The methodology between this study and that by Gumz and Weller (2005) also differed. Our study used peppermint in a simulated dormant state and a greenhouse growing environment, whereas the study by Gumz and Weller (2005) relied upon naturally induced dormant peppermint and spearmint grown under field conditions. In an extension publication, Weller et al. (2000) suggested that dormancy occurs following one or more killing frost. Gillespie and Volaire (2017) agreed that vegetative winter dormancy of herbaceous perennials can be induced by freezing temperatures, soil heaving, and ice encasement. However, Gillespie and Volaire (2017) also concluded more generally that winter dormancy is signaled by decreasing photoperiod and temperature and marked by 1) decrease or cessation of growth, 2) senescence of aboveground foliage, 3) preceding development of storage organs, and 4) reduction of metabolic activity. We do not presume that our simulated dormancy is equivalent to dormancy experienced under field conditions. However, we do believe it is a good faith proxy for dormancy under greenhouse research conditions.

By 8 WAT, the lowest mesotrione rate resulted in 8% crop injury and 88% of the height of the nontreated control. Nevertheless, the predicted dry weight at the lowest mesotrione rate was unacceptably low (60% of the nontreated control). That constituted a 40% reduction of yield, whereas a standard threshold loss for farmers ranges from 5% to 10%. Based on these findings, no rate of mesotrione applied in this study was safe for peppermint due to a reduction in biomass. However, under field conditions it is possible to have reduced peppermint hay yield without a corresponding reduction in oil yield (S. L. Meyers, unpublished data). Field trials with dormant application of mesotrione should be conducted to confirm these findings and determine the impact of mesotrione on peppermint oil yield. Additional research should be conducted to evaluate other Group 27 herbicides or herbicides with other modes of action not currently registered for use on peppermint.

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Practical Implications

Results from this study suggest that mesotrione applied even at a low rate (53 g ai ha^{-1}) to simulated dormant peppermint resulted in significant (40%) crop yield reduction. Mesotrione is not registered for use on peppermint crops in Indiana, but it is for corn (*Zea mays* L.), and many Indiana mint growers also grow corn. Growers who apply mesotrione-containing herbicides to corn should follow proper sprayer cleaning procedures to avoid potential tank contamination applications to peppermint. Given the sensitivity of peppermint to mesotrione in this study, it may also be advisable to avoid establishing new peppermint fields following corn if a late-season application of mesotrione was made to the previous corn crop.

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