Weed Control Efficacy and Ornamental Plant Tolerance to Dimethenamid–p + Pendimethalin Granular Herbicide[1]

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Abstract

Weed control efficacy and ornamental plants tolerance to dimethenamid–p (0.75%) + pendimethalin (1%) granular herbicide was evaluated in flat tray-grown weeds and container-grown ornamental plants. Dimethenamid – p + pendimethalin at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) controlled the tested broadleaf and grassy weeds >80% for up to 8 wk following herbicide application. The higher dimethenamid–p + pendimethalin rates of ≥5.88 kg ai·ha^{-1} (≥5.25 lb ai·A^{-1}) provided 94% to 99% control of the tested weed species but caused commercially unacceptable injury to pygmyweed [*Crassula radicans* (Haw.) D. Dietr. 'Red carpet']. Chocolate flower (*Berlandiara lyrata* Benth.) tolerated dimethenamid–p + pendimethalin at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) and 5.88 kg ai·ha^{-1} (5.25 lb ai.A^{-1}) but the 11.77 kg ai ·ha^{-1} (10.5 lb ai.A^{-1}) rate was injurious in one of the two study years. Leucothoe [*Leucothe fontanesiana* (Steudel) Sleumer 'Rainbow'] showed excellent tolerance to dimethenamid–p + pendimethalin at rates up to 11.77 kg ai·ha^{-1} (10.5 lb ai ·A^{-1}).

Herbicides used in this study: 0.75% Dimethenamid–p + 1% pendimethalin (Freehand 1.75 G), (*S*) 2-chloro-N-(2,4-dimethylthiophen-3-yl)-N-[(2S)-1-methoxypropan-2-yl]acetamide] + N-(1-ethylpropyl)-3,4-dimethyl-2,6- dinitrobenzenamine].

Ornamental plant species used in this study: chocolate flower (*Berlandiara lyrata* Benth.), leucothoe [*Leucothe fontanesiana* (Steudel) Sleumer 'Rainbow'], and pygmyweed [*Crassula radicans* (Haw.) D. Dietr. 'Red Carpet'].

Weed species used in this study: barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], fringed willowherb (*Epilobium ciliatum* Raf. ssp. *ciliatum*), giant foxtail (*Setaria faberi* Hermm.), goosegrass [*Elusine indica* (L.) Gaertn.], hairy bittercress (*Cardamine hirsuta* L.), large crabgrass [*Digitaria sangunalis* (L.) Scop.], redroot pigweed (*Amaranthus retroflexus L.*), and yellow woodsorrel (*Oxalis stricta* L.).

Index words: container-grown, ornamental plant tolerance, preemergence herbicide, weed management, weeds.

Significance to the Horticulture Industry

Dimethenamid–p (0.75%) + pendimethalin (1%) granular herbicide provides two modes of action, a microtubule inhibitor (pendimethalin) and a long-chain fatty acid inhibitor (dimethenamid–p), for a broad spectrum weed control in ornamental plants. An herbicide with two modes of action would also reduce the chances of herbicide resistance evolution in weeds. The maximum single application rate for dimethenamid–p + pendimethalin granular herbicide is 3.92 kg ai·ha^{-1} (3.50 lb ai·A^{-1}). In the current study, grassy and broadleaf weeds were controlled >80% for up to 8 wk with 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) of dimethenamid–p + pendimethalin. The higher rates of ≥5.88 kg ai·ha^{-1} (≥5.25 lb ai·A^{-1}) were more effective with 94% to 99% control of the tested weed species but were not safe on every ornamental species tested. The 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}) rates are above the maximum labeled rates. These rates were adopted from a previous IR-4 crop safety protocol for ornamental plant species used in this study. The ornamental plant tolerance also varied with the experimental year and the species tested. For leucothoe var. 'Rainbow', dimethenamid–p + pendimethalin did not cause injury at rates up to 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}). Chocolate flower was injured only in one of the two study years. However, the injury levels were within the commercially acceptable limits with dimethenamid–p + pendimethalin rates of 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) and 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}). Pygmyweed var. 'Red carpet' was severely injured by dimethenamid–p + pendimethalin at rates >2.94 kg ai.ha^{-1} (2.62 lb ai.A^{-1}). Therefore, dimethenamid–p + pendimethalin granular herbicide is not recommended for use in pygmyweed var. 'Red Carpet'.

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Introduction

Weed competition for resources can significantly reduce ornamental plant growth and development (Berchielli-Robertson et al. 1990, DiTomasso 1995, Sands and Nambiar 1984). Poor crop growth impairs the aesthetic value and thus, adversely affect the salability of ornamental pants (Simpson et al. 2002). Often, as few as one weed plant in a pot can significantly reduce the growth of a container-grown ornamental plant (Fretz 1972, Walker and Williams 1989). For example, a single large crabgrass [*Digitaria sanguinalis* (L.) Scop.] plant reduced the growth of 'Convexa' Japanese holly (*Ilex crenata* Thunb.'Convexa') by 60% (Fretz 1972). Similarly, the growth of Fashion azalea (*Rhododendron* x 'Fashion') was reduced 43% by one eclipta (*Eclipta prostrata* L.) plant (Berchielli-Robertson et al. 1990).

Controlling weeds in container-grown ornamental plants is not only challenging but also very expensive. Economic losses resulting from weed competition with container-grown ornamentals have been estimated at $17,300 per ha ($7,004 per acre) (Case et al. 2005). Mathers (2003) reported that manual weed removal costs were as high as $9,900 per ha. Similarly, Darden and Neal (1999) reported that hand weeding over a 4-month period cost about $1,370 for one thousand 3-L pots. Weatherspoon and Curry (1973) reported that weeding costs were $3,600 per 0.4 ha (1 acre) when herbicides were not used; therefore, preemergence herbicides are required to reduce the production costs.

Ornamental nursey managers use multiple weed management tactics such as hand weeding, herbicides, mulching, sanitation, or their various combinations for raising weed-free plants (Chong 2003, Neal et al. 2017, Norcini et al. 2006, Richardson et al. 2008). Cultural and mechanical weed control methods are costly and time and labor intensive. Contrarily, preemergence herbicides offer broad spectrum, economical, and long duration weed control but there is an inherent risk for crop injury. Most container nursery growers make two to six applications of granular preemergence herbicides, at 8 to 10 wk interval, per year (Gilliam et al. 1990, Judge et al. 2004).

Currently, weeds in the container-grown ornamental plants are controlled mainly through a combination of hand weeding and application of preemergence herbicides (Altland et al. 2004). Use of herbicides for managing weeds in container nurseries has become standard practice since the early 1970's. However, a limited number of herbicides is available for managing weeds in ornamental plants (Case et al. 2005, Cole 1999). Preemergence herbicide options for selective control of broadleaf weeds are still limited. In the last decade, several preemergence herbicides have been registered for managing weeds in ornamental plants. One of these preemergence herbicides is a granular combination product containing dimethenamid–p (0.75%) + pendimethalin (1%). Dimethenamid–p + pendimethalin granular herbicide is registered for preemergence control of a broad spectrum of broadleaf weeds, grasses, and sedges in container-grown and landscape ornamentals. Dimethenamid–p is a long-chain fatty acid-inhibitor and pendimethalin is a root and shoot growth-inhibitor. Dimethenamid–p + pendimethalin can be applied to newly planted or established field- or container-grown ornamentals. The maximum single application rate is 3.92 kg ai·ha^{-1} (3.50 lb ai·A^{-1}) and a maximum seasonal application rate is 7.85 kg ai·ha^{-1} (7.0 lb ai·A^{-1}).

Each year thousands of new ornamental plant species and varieties are commercialized. This warrants the continued evaluation of new as well as the older preemergence herbicides for ornamental plant safety. The objectives of this research were to evaluate dimethenamid–p + pendimethalin granular herbicide for preemergence weed control efficacy on flat tray-grown weeds and tolerance of container-grown ornamental plants.

Materials and Methods

Weed efficacy. Weed species response to dimethenamid–p (0.75%) + pendimethalin (1%) granular herbicide was evaluated at the Valley Laboratory of the Connecticut Agricultural Experiment Station in Windsor, CT. The experiment was initiated on June 22, 2017 and was repeated on May 25, 2018. Twenty-four flat trays (52 × 26 × 6 cm) were filled with Pro-Mix Premium All Purpose planting media (200 Kelly Rd, Quakertown, PA 18951). Pro-Mix Premium All Purpose contains Canadian sphagnum peat moss (80-90%), peat humus, perlite, limestone, and mycorrhizae PTB297 technology. Trays were watered using 1.2 cm (0.5 in) overhead mist irrigation and the substrate was allowed to settle for two days. On June 24, 2017 and May 27, 2018, dimethenamid–p + pendimethalin (Freehand®; BASF Corp., Research Triangle Park, NC) granular herbicide was applied at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}) with a hand-held shaker bottle. Each dimethenamid–p + pendimethalin treatment was applied to six flat trays; three for the broadleaf weed species mixture and three for the grassy weed species mixture. After herbicide application, trays were placed back in a greenhouse under the overhead mist irrigation system and 1.2 cm irrigation was applied. Approximately 4-hr after overhead irrigation, 50 seeds each of fringed willowherb (*Epilobium ciliatum* Raf. ssp. *ciliatum*), hairy bittercress (*Cardamine hirsuta* L.), redroot pigweed (*Amaranthus retroflexus L.*), and yellow woodsorrel (*Oxalis stricta* L.) were mixed together and applied to the surface of twelve flat trays with a shaker bottle. Similarly, 50 seeds of each of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], giant foxtail (*Setaria faberi* Hermm.), goosegrass [*Elusine indica* (L.) Gaertn.], and large crabgrass [*Digitaria sangunalis* (L.) Scop.] were applied to the surface of a different set of twelve flat trays. A nontreated control (three trays) was also included, separately for broadleaf and grassy weeds, for treatment comparison. The experiment was established in a completely randomized design with three replications per treatment. Jacks Professional General Purpose (JR Peters Inc., Allentown, PA) soluble fertilizer (20N– $20P_2O_5$ – $20K_2O$) was applied weekly at 300 ppm beginning two weeks after weed emergence until harvested for fresh biomass. An overhead mist irrigation of 1.2 cm was applied daily in four cycles of 4 min each with a 3 h gap between cycles. Weed control was evaluated by separately counting the weed species at 4 and 8 wk after seeding (WAS) and data were converted to percent control compared to the nontreated control. At 8 WAS, all weeds, where present, were harvested from each flat tray and the combined shoot fresh biomass was recorded.

Ornamental plant tolerance. The granular herbicide dimethenamid–p (0.75%) + pendimethalin (1%) was evaluated for crop safety on a variety of ornamental species. The experiments were conducted at the Valley Laboratory of the Connecticut Agricultural Experiment Station in Windsor, CT in 2017 and 2018. Three ornamental plant species evaluated for tolerance to dimethenamid–p + pendimethalin were: chocolate flower (*Berlandiara lyrata* Benth.), leucothoe [*Leucothe fontanesiana (*Steudel) Sleumer 'Rainbow'], and pygmyweed [*Crassula radicans* (Haw.) D. Dietr. 'Red Carpet']. Chocolate flower is an herbaceous perennial prized for its

Table 1. Percent broadleaf weed control 4 and 8 wk after application of dimethenamid–*p* (0.75%) + pendimethalin (1%) granular herbicide[z].

Active ingredient		Hairy bittercress		Fringed willowherb		Redroot pigweed		Yellow woodsorrel	
kg ai.ha^{-1}	lb ai.A^{-1}	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
		%							
2.94	2.62	98 a[y]	92 b	93 b	88 b	97 a	91 b	93 b	87 b
5.88	5.25	99 a	99 a	99 a	94 ab	98 a	97 ab	99 a	94 ab
11.77	10.5	99 a	99 a	99 a	99 a	99 a	98 a	99 a	99 a

[z]Dimethenamid–*p* (0.75%) + pendimethalin (1%) (Freehand®, BASF Corp., Research Triangle Park, NC); granular herbicide treatments were applied with a hand-held shaker bottle approximately 4 hours before planting weed seeds. A 1.2-cm overhead irrigation was provided immediately after herbicide application.

[y]Means followed by the same letter within a column are not significantly different using the Fisher's protected least square difference at $\alpha = 0.05$. Data averaged over two years.

sweet, chocolate-scented flowers. It is commonly grown as a border plant or as a ground cover. Leucothoe is an evergreen, low-growing, perennial shrub which is valued for its variegated foliage and pollinator attraction. Leucothoe is planted as a groundcover or a border plant in the landscape areas. Pygmyweed is a perennial, mat-forming succulent that is commonly grown as a ground cover in landscapes.

Plugs of leucothoe [15-cm tall (6 in)], chocolate flower [10-cm tall (4 in)], and pygmyweed [6-cm tall 2.4 in)] were planted. All ornamental plant species were transplanted on June 9, 2017 into 2.9 L (3 qt) (C350; Nursery Supplies Inc., Chambersburg, PA) containers filled with composted pine bark, leaf compost, and woodchips (2:1:1) mixture by volume. The potting substrate was amended (per 0.76 m^3 or 1 yd^3) with 3.74 kg (8.24 lb) 20N-4P-8K controlled-release fertilizer (Harrells Profertilizer; Harrells LLC, Lakeland, FL), 0.15 kg (0.33 lb) booster micronutrients (Harrells LLC, Lakeland, FL), and 2.27 kg (5.0 lb) dolomitic limestone (Plant Products LLC, Findley, OH). Containers were kept on an outdoor gravel pad. In 2018, the experiments were repeated and the ornamental species were transplanted on May 23, 2018 into the same sized containers and similar substrates as previously described.

The experiment was arranged in a completely randomized design with 12 replications per treatment. Dimethenamid–p + pendimethalin granular herbicide was applied within 7 d after transplanting at 0, 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}), with a hand-held shaker bottle and a second application was made approximately 6 wk after the initial application. These rates were adopted from a previous IR-4 crop safety research protocol. The maximum single application rate for dimethenamid–p + pendimethalin granular herbicide is 3.92 kg ai·ha^{-1} (3.50 lb ai·A^{-1}). The 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}) rates are above the maximum labeled rates. All plants received 1.2-cm irrigation within an hour of treatment application and daily afterwards. Phyto-toxicity ratings for chlorosis, necrosis, and stunting injury were recorded at 4 wk after each application on a 0 to 10 scale with 0 = no damage, 1 = minor (10%), 2 = moderate (20%), 2–4 = severe (20% to 40%), 5–9 = extreme (50% to 90%), and 10 = dead plant. Plant height and average width (width at the widest point + perpendicular width / 2) were recorded at 6 wk after the second application.

Statistical analyses. Data on various response variables were analyzed with a generalized linear mixed model methodology using the GLIMMIX procedure in SAS (Version 9.3; SAS Institute, Inc., Cary, NC). Before the ANOVA test, data were tested for normality using PROC UNIVARIATE and homogeneity of variance with the modified Levene test. The weed efficacy and fresh biomass data were analyzed separately by wk after treatment (WAT). The weed efficacy data were arcsine-transformed and the fresh biomass data were square-root transformed for correcting non-normality and heterogeneity of variance. However for simplicity, the back transformed means are discussed and presented in the tables. Ornamental plant injury data from the first and the second application were analyzed separately. Year and dimethenamid–p + pendimethalin rate were treated as fixed effects whereas replication and its interactions with fixed effect factors were considered as random effects. Means were separated with Fisher's protected least square difference at $\alpha = 0.05$.

Results and Discussion

Broadleaf weed control. The herbicide rate x broadleaf weed species interaction was significant (p=0.011), which suggested that control varied with the weed species and dimethenamid–p + pendimethalin rate. At 4 WAT, hairy bittercress and redroot pigweed were controlled 97% to 99% without a significant dimethenamid–p + pendimethalin rate effect (Table 1). However, fringed willowherb and yellow woodsorrel control increased significantly from 93% at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), to 99% at ≥5.88 kg ai·ha^{-1} (≥5.25lb ai·A^{-1}). At 8 WAT, all tested weed species were still controlled ≥87% with dimethenamid–p + pendimethalin at 2.94 kg ai.ha^{-1} (2.62 lb ai.A^{-1}). At 5.88 kg ai·ha^{-1} (5.25lb ai·A^{-1}) or higher rates, control was in the 94% to 99% range.

Dimethenamid–p + pendimethalin efficacy may vary with the substrate type (Robertson and Derr 2017). Stewart et al. (2019) reported differential control of yellow woodsorrel with dimethenamid–p in different substrates. In one experiment they achieved excellent yellow woodsorrel control regardless of substrate type. However, in another similar experiment they reported differences in ED_{80} values for dimethenamid–p across substrates (peat, 0-month aged pine bark, and standard pine bark) for yellow woodsorrel control. The ED_{80} was significantly higher in both peat (ED80= 2.82 kg ai·ha^{-1} or 2.51 lb ai.A^{-1}) and 0-

Table 2. Percent grassy weed control 4 and 8 wk after application of dimethenamid–*p* (0.75%) + pendimethalin (1%) granular herbicide[z].

Active ingredient		Barnyardgrass		Giant foxtail		Goosegrass		Large crabgrass	
kg ai.ha^{-1}	lb ai.A^{-1}	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
		%							
2.94	2.62	98[y] a	86 b	99 a	91 b	98 a	82 b	99 a	89 b
5.88	5.25	99 a	97 a	99 a	96 ab	99 a	94 a	99 a	98 a
11.77	10.5	99 a	99 a	99 a	99 a	99 a	99 a	99 a	99 a

[z]Dimethenamid–*p* (0.75%) + pendimethalin (1%) (Freehand®, BASF Corp., Research Triangle Park, NC); granular herbicide treatments were applied with a hand-held shaker bottle approximately 4 hours before planting weed seeds. An 1.2-cm overhead irrigation was provided immediately after herbicide application.

[y]Means followed by the same letter within a column are not significantly different using the Fisher's protected least square difference at $\alpha = 0.05$. Data averaged over two years.

month (ED80= 3.06 kg ai·ha^{-1} or 2.72 lb ai·A^{-1}) substrates compared with the standard (ED80= 1.86 kg·ai·ha^{-1} or 1.66 lb ai·A^{-1}), indicating that a higher rate of dimethenamid–p was needed in peat and the 0-month pine bark substrate. Wallace and Hodges (2007) observed variable control of Palmer amaranth [*Amaranthus palmeri* (L.) Swat], a similar pigweed species in the *Amaranthaceae* family, with dimethenamid–p in field-grown 'Red President' cannas. Palmer amaranth control decreased from 90% at 6 WAT to 43% at 10 WAT in 2003 but increased from 58% to 95% in 2004. Greater than 90% control of problematic broadleaf weed species such as kochia (*Kochia scoparia* L.) and Palmer amaranth has been reported with dimethenamid–p or dimethenamid–p + pendimethalin (Kumar and Jha 2015a; Kouame et al. 2022).

The combined broadleaf weed fresh biomass data at 8 WAT conformed to the percent weed control results. The average combined broadleaf weed fresh biomass in the nontreated control was 156 g per tray. The average fresh weed biomass was 24.6, 6.2, and 1.2 g per tray with dimethenamid–p + pendimethalin at 2.94 kg ai·ha^{-1} (2.62 lb ai.A^{-1}), 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}). This was 84%, 96%, and 99% less compared to the nontreated control. Excellent (>81%) control of hairy bittercress has earlier been reported 90 d after pendimethalin application at 1.1 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) in a pot-in-pot production in Mississippi (Fare et al. 2005). Comparatively in the current study, there were 1.68 kg ai·ha^{-1} (1.5 lb ai·A^{-1}) of pendimethalin in 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) of dimethenamid–p + pendimethalin.

Grassy weed control. No differences were observed in the level of control for any grassy weed species with dimethenamid–p + pendimethalin rate at 4 WAT (Table 2). All grassy weeds were controlled 98% or higher with dimethenamid–p + pendimethalin at ≥2.94 kg ai·ha^{-1} (≥2.62 lb ai·A^{-1}). However at 8 WAT, an herbicide rate effect was significant (p=0.036). Control decreased to 82% for goosegrass, 86% for barnyardgrass, 89% for large crabgrass, and 91% for the giant foxtail with 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}). All grassy weeds were still in the 94% to 99% control range without differences between the 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}) and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}) rates.

Previously, Robertson and Derr (2017) reported excellent control of southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.] with dimethenamid–p applied at 1.7 kg ai·ha^{-1} (1.52 lb ai·A^{-1}), pendimethalin at 3.7 kg ai·ha^{-1} (3.3 lb ai·A^{-1}), and dimethenamid–p + pendimethalin at 3.9 kg ai·ha^{-1}(3.47 lb ai·A^{-1}). They also reported higher smooth crabgrass control with dimethenamid–p at 1.7 kg ai·ha^{-1} (1.52 lb ai·A^{-1}) in a pine bark substrate than in the field soil. In contrast, pendimethalin at 3.7 kg ai·ha^{-1} (3.3 lb ai·A^{-1}) or dimethenamid–p + pendimethalin at 3.9 kg ai.ha^{-1} (3.47 lb ai·A^{-1}) were more effective on smooth crabgrass in field soil. This was attributed to increased potential for dimethenamid–p leaching in field soil than pine bark (Robertson and Derr 2017) while pendimethalin leached more in pine bark than field soil. Patrick et al. (2017) reported differences in goosegrass control with dimethenamid–p applied at 1.68 kg ai·ha^{-1} (1.50 lb ai·A^{-1}). At 7 months after treatment, goosegrass control was <50% in 2011 but ≥90% in 2012. In the current study, dimethenamid–p rates were 1.277 kg ai·ha^{-1} (1.14 lb ai·A^{-1}), and 5.107 kg ai·ha^{-1} (4.56 lb ai·A^{-1}), in 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1}(10.5 lb ai·A^{-1}) of dimethenamid–p + pendimethalin, respectively.

The fresh biomass data at 8 WAT showed similar herbicide rate differences (p=0.042). The average combined fresh biomass at 8 WAT was 327 g per tray for the nontreated control. The fresh biomass was 54.8, 9.6, and 2.1 g per tray with dimethenamid–p + pendimethalin at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}), respectively. This was 83%, 97%, and 99% less compared to the nontreated control.

Ornamental plant tolerance. For chocolate flower, a year by dimethenamid–p + pendimethalin rate effect was highly significant (p<0.0153). Injury occurred only in 2017 and was rated the highest at 4 wk after the first and second application (Table 3). Following the first application, the injury symptoms included necrotic spots on leaves, leaf malformation (crinkling of the leaves), and growth stunting. Injury form dimethenamid–p + pendimethalin applied at 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}) was rated 2.5 (25%) which was higher than 0.7 (7%) and 1.5 (15%) with 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) and 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), respectively (Table 3). Following the second application, only stunting injury was observed and was rated 1.4 (14%), 1.6 (16%), and 2.0 (20%) with 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}), 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}), and 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}), respectively (Table 3). These results showed that dimethenamid–p + pendimetha-

Table 3. Ornamental plant injury 4 wk after the first and second application of dimethenamid–*p* (0.75%) + pendimethalin (1%) granular herbicide[z].

Active ingredient		First application		Second application	
kg $ai.ha^{-1}$	lb $ai.A^{-1}$	Chocolate flower	Pygmyweed	Chocolate flower[y]	Pygmyweed
2.94	2.62	0.7 b[x]	0.5 c	1.4 b	0.8 c
5.88	5.25	1.5 b	2.7 b	1.6 ab	3.1 b
11.77	10.5	2.5 a	4.2 a	2.0 a	4.7 a

[z]Dimethenamid–*p* (0.75%) + pendimethalin (1%) (Freehand®, BASF Corp., Research Triangle Park, NC); the first application was made within 7 d after transplant and a second application was applied about 6 wk after the first application using a hand-held shaker. An 1.2-cm overhead irrigation was provided immediately after herbicide application.

[y]Only stunting injury occurred in chocolate flower following the second application. Injury ratings (0 = no injury, 5 >45% injury, 10 = dead plant). Injury data (0–10: 0 = no damage, 1 = minor (10%), 2 = moderate (20%), 3–4 = severe (30% to 40%), 5–9 = extreme (50% to 90%), and 10 = dead plant).

[x]Means followed by the same letter within a column are not significantly different using the Fisher's protected least square difference at $\alpha = 0.05$. Data averaged over two years.

lin at 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$) or 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$) caused little to no injury to newly transplanted chocolate flower. The highest rate of 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$) was marginally injurious. An injury rating of 2.0 (20%) on a 0 to 10 rating scale is considered to be mild and is commercially acceptable.

Final plant height and width data also revealed a similar response of chocolate flower to different rates of dimethenamid–p + pendimethalin. Averaged over years, the final plant height measurements were: 36 cm, 35 cm, 33 cm, and 29 cm with dimethenamid–p + pendimethalin rates of 0 kg $ai{\cdot}ha^{-1}$ (nontreated control), 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$), 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$), and 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$), respectively (Table 4). Similarly, the final width measurements were: 23 cm, 25 cm, 22 cm, and 20 cm with dimethenamid–p + pendimethalin rates of 0 kg $ai{\cdot}ha^{-1}$ (nontreated control), 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$), 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$), and 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$), respectively (Table 4).

As for leucothoe, no chlorotic, necrotic, or stunting injury was observed in either experimental year. This showed that dimethenamid–p + pendimethalin granular herbicide did not injure leucothoe at rates up to 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$) when two sequential applications were made at 6 wk intervals. Final plant height and width data (Table 4) also conformed to the visual injury ratings. Averaged over years and dimethenamid–p + pendimethalin rates, final plant height and width measurements for leucothoe were 27 cm and 24 cm, respectively.

Injury to pygmyweed from dimethenamid–p + pendimethalin granular herbicide was significant (p=0.0017). Injury symptoms comprised necrotic lesions on leaves, malformation of terminal buds, reddening of leaves and stems, and stunted growth. Injury was the highest at 4 wk after each application (Table 3). Dimethenamid–p + pendimethalin applied at 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$) was the most injurious treatment with the severe injury ratings of 4.2 (42%) and 4.7 (47%) following the first and second application, respectively. This was significantly higher than injury ratings of 0.5 (5%) and 0.8 (8%) with 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$) and injury ratings of 2.7 (27%) and 3.1 (31%) with 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$) following the first and the second application, respectively. Similarly, dimethenamid–p + pendimethalin at 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$) was more injurious to pygmyweed than at 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$). In this study, two applications of dimethenamid–p + pendimethalin at 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$) made at 6 wk interval caused little to no injury to pigmyweed. This rate was lower than the maximum single application rate of 3.92 kg $ai{\cdot}ha^{-1}$ (3.50 lb $ai{\cdot}A^{-1}$). For an ornamental plant to be considered tolerant it must tolerate at least two-time the maximum single application rate of an herbicide (to allow for application overlaps). Therefore, dimethenamid–p + pendimethalin granular herbicide failed in meeting the minimum crop tolerance requirement to be considered safe on pygmyweed.

Similar trends were observed in pygmyweed final plant height and width measurements with different rates of dimethenamid–p + pendimethalin granular herbicide (Table 4). Averaged over years, final plant height measurements were: 13 cm, 13 cm, 9 cm, and 8 cm with dimethenamid–p + pendimethalin rates of 0 kg $ai{\cdot}ha^{-1}$ (nontreated control), 2.94 kg $ai.ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$), 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$), and 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$), respectively. Similarly, the final width measurements were: 12 cm, 12 cm, 9 cm, and 9 cm with dimethenamid–p + pendimethalin rates of 0 kg $ai{\cdot}ha^{-1}$ (nontreated control), 2.94 kg $ai{\cdot}ha^{-1}$ (2.62 lb $ai{\cdot}A^{-1}$), 5.88 kg $ai{\cdot}ha^{-1}$ (5.25 lb $ai{\cdot}A^{-1}$), and 11.77 kg $ai{\cdot}ha^{-1}$ (10.5 lb $ai{\cdot}A^{-1}$), respectively.

Table 4. Final plant height and width of ornamental plant species 6 wk after the second application of dimethenamid–*p* (0.75%) + pendimethalin (1%) granular herbicide[z].

Active ingredient		Height (cm)			Width (cm)		
kg $ai.ha^{-1}$	lb $ai.A^{-1}$	Chocolate flower	Leucothoe	Pygmyweed	Chocolate flower	Leucothoe	Pygmyweed
0	0	36[y] a	27 a	13 a	23 a	24 a	12 a
2.94	2.62	35 a	28 a	13 a	24 a	23 a	12 a
5.88	5.25	33 ab	27 a	9 b	22 ab	25 a	9 b
11.77	10.5	29 b	26 a	8 b	20 b	24 a	9 b

[z]Dimethenamid–*p* + pendimethalin (Freehand®, BASF Corp., Research Triangle Park, NC); the first application was made within 7 d after transplant and a second application was applied about 6 wk after the first application using a hand-held shaker.

[y]Means followed by the same letter within a column are not significantly different using the Fisher's protected least square difference at $\alpha = 0.05$. Data averaged over two years.

This study showed that the granular herbicide dimethenamid–p + pendimethalin at 2.94 kg ai·ha^{-1} (2.62 lb ai·A^{-1}) can effectively control tested grassy and broadleaf weeds without risk for significant injury to chocolate flower and 'Rainbow' leucothoe. This rate was 0.98 kg ai·ha^{-1} (0.88 lb ai·A^{-1}), lower than the maximum single application rate of 3.92 kg ai·ha^{-1} (3.50 lb ai·A^{-1}). The control of the tested weed species improved with dimethenamid–p + pendimethalin rates $\geq$5.88 kg ai·ha^{-1} ($\geq$5.25 lb ai·A^{-1}) but higher rates caused unacceptable injury to some of the ornamental species tested. For example, leucothoe var. 'Rainbow' was extremely tolerant to dimethenamid–p + pendimethalin rates up to 11.77 kg ai·ha^{-1} (10.5 lb ai·A^{-1}). In chocolate flower, the injury levels were within the commercially acceptable limits with dimethenamid–p + pendimethalin rates up to 5.88 kg ai·ha^{-1} (5.25 lb ai·A^{-1}). For pygmyweed var. 'Red carpet', the dimethenamid–p + pendimethalin was highly injurious and therefore, should be avoided.

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