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Postemergence Herbicides for Calendula

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Calendula is an alternative oilseed crop whose seed oil is valued as a substitute for tung oil and a replacement for petroleum-based volatile organic compounds in paints and other coatings. Calendula tolerances to most POST-applied herbicides are unknown. Two POST-applied herbicides were tested for tolerance by calendula. Imazamethabenz at 0.44 kg ai ha^{-1} plus surfactant and desmedipham plus phenmedipham at 0.36 + 0.36 kg ai ha^{-1} were tolerated by calendula, but the latter herbicide must be applied after the four–leaf-pair stage of growth to avoid severe injury. Neither herbicide adversely affected calendula seed yield if applied at the four–leaf-pair stage. Because these herbicides can control several weed species, calendula tolerance to them may encourage more growers and crop advisors to test this new oilseed crop on commercial farms.

Nomenclature: Desmedipham; imazamethabenz; phenmedipham; calendula, *Calendula officinalis* L.
Key words: Calendic acid, drying oil, herbicide injury, industrial crop, oilseed, tolerance.

Calendula officinalis (calendula) es un cultivo oleaginoso alternativo cuyo aceite es valorado como un sustituto del aceite de tung y como remplazo para compuestos volátiles derivados del petróleo usados en pinturas y selladores. La tolerancia de calendula a la mayoría de los herbicidas aplicados POST es desconocida. Se evaluó la tolerancia de calendula a dos herbicidas aplicados POST. Imazamethabenz a 0.44 kg ai ha^{-1} más surfactante y desmedipham más phenmedipham a 0.36 + 0.36 kg ai ha^{-1} fueron tolerados por calendula, pero este último tratamiento con herbicidas debe ser aplicado después de que el cultivo ha alcanzado el estado de desarrollo de cuatro pares de hojas para evitar daños severos. Ningún herbicida afectó adversamente el rendimiento de semilla de calendula si la aplicación se hizo en dicho estado de desarrollo. Debido a que estos herbicidas pueden controlar varias especies de malezas, la tolerancia de calendula a ellos puede motivar a más productores y asesores agrícolas a probar este nuevo cultivo oleaginoso en fincas comerciales

Products containing volatile organic compounds (VOCs) are used as diluents in paints, varnishes, and other coatings. In the atmosphere, VOCs can combine with nitrogen oxides in the presence of sunlight and form ozone and ground-level smog. For this reason the use of VOC-laden products is being restricted in states such as California (Anonymous 2009) and throughout Europe (Geldermann and Rentz 2005). Natural drying oils can replace petroleum-based VOCs. These oils polymerize as they cure rather than volatilize and, thereby, do not contribute to ozone and smog formation. The rising need for VOC replacements could place demands on drying oils that may not be met by current sources, such as tung oil and linseed oil (Muuse et al. 1992).

Tung oil contains the reactive fatty acid known as eleostearic acid, which bestows its characteristic drying properties. Tung oil is derived from the seeds of the tung tree (*Aleurites fordii* Hemsley). Tung trees originated in southeastern Asia but now are grown in other subtropical regions as well (Axtell and Fairman 1992). However, tung oil production may not be sufficient to fulfill expected replacement needs for VOCs.

Linseed oil is derived from flax (*Linum usitatissimum* L.). It contains high levels of linolenic acid. Historically, linseed oil has been the most commonly used drying oil worldwide. Petroleum replaced much of the linseed oil in paints during the 1900s, which caused a decrease in flax production. However, flax production has increased in North America recently, but mostly due to its value for human health rather than as an industrial oil (Berglund 2002). Thus, linseed oil possibly could replace VOC in paints based on the production potential of flax in temperate agricultural zones. However, linseed oil does not dry as quickly as tung oil (Wheeler 1950), which makes it a less valuable substitute (Bierman et al. 2010).

Calendula oil, which contains high levels of calendic acid, is another alternative drying oil (Biermann et al. 2010). It is produced by seeds of the annual herbaceous plant calendula, or pot marigold (*Calendula officinalis* L.). Few other drying oils polymerize as quickly as does calendula oil (Derksen et al. 1996). Moreover, calendula grows well in temperate climates, whereas the tropical tung tree does not. Therefore, calendula possibly could serve as a substitute for tung trees, as well as an improvement compared to flax. If calendula can be grown successfully as a crop, then temperate economies would have a ''domestic'' source of a highly sought-after drying oil.

Another process for obtaining specialty fatty acids is to engineer standard commodity crops genetically. However, efforts to engineer calendic acid synthesis in soybean have met with bottlenecks not yet overcome (Cahoon et al. 2007). Consequently, the need continues for the further domestication of calendula oilseed varieties. For this reason a large project, known as CARMINA, was sponsored by the European Union in the 1990s. Agronomic results of this project were summarized in the form of a calendula growers guide (Froment et al. 2003) and a summary article (Cromack

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and Smith 1998). Most current calendula varieties are ornamentals, but a few oilseed varieties exist, e.g., 'Carola' was released in 2005. Oilseed varieties produce up to 3,000 kg seeds ha^{-1} in temperate Europe and New Zealand (Martin and Deo 2000), and their seeds contain ≥ 20% oil. Fertilizer requirements are relatively low, e.g., only about 50 kg N ha^{-1}. Few troublesome insects and diseases are known, although a disease exhibiting aster yellows–like symptoms can be a problem (Callan et al. 2008). Thus, overall, calendula could be considered as a "low-input" crop. To date, its primary agronomic and management constraints center on weed control during the growing season.

A small number of mostly PPI/PRE-applied herbicides are known to be safe on calendula (Cromack and Smith 1998; Froment et al. 2003). Chlorpropham, DCPA (= chlorthal-dimethyl), isoxaben, metamitron, pronamide (= propyzamide), propachlor, and trifluralin were consistently safe in northern Europe, whereas metazachlor and pendimethalin sometimes injured calendula. Only two POST-applied herbicides for calendula were identified: asulam was consistently safe, whereas phenmedipham sometimes injured calendula. Most of these products (asulam, DCPA, isoxaben, metamitron, metazachlor, pronamide, and propachlor) are used sparingly or not at all in the United States (Anonymous 2007a,b, 2008), and their sales have been negligible in recent years in Minnesota (Anonymous 2011). Thus, both crop tolerance and herbicide availability could present challenges to regional growers who might consider growing calendula as an alternative crop. Additional options for weed control would be needed if calendula were to be grown widely in the north-central region of the United States. Because grass weeds are controlled easily in calendula with any of several grass-specific herbicides, and because growers tend to prefer POST-applied products, the objective of this study was to test POST-applied broadleaf herbicides commonly used in the north-central region of the United States that are tolerated by calendula.

Materials and Methods

Greenhouse Testing. Herbicide screening experiments occurred during winter through spring, 2009, in the U.S. Department of Agriculture–Agricultural Research Service greenhouse facilities in Morris, MN. Four "nugget-type" seeds (Breemhaar and Bouman 1995) of the oilseed variety Carola were sown 2 cm deep in 10 by 10–cm pots filled with a peat–sand–loam (30–30–40) soil. Pots were placed in a greenhouse with a day/night temperature setting of 25/15 C and natural day length with maximum solar radiation of approximately 400 μmol m^{-2} sec^{-1}. Pots were watered daily and fertilized weekly with a complete nutrient solution. Pots were thinned to two seedlings each prior to herbicide application, at which time plants were at the one– to four–leaf-pair stages of growth. Although not strictly opposite from one another, true leaves tend to emerge in pairs in calendula. Henceforth, early growth stages are described in terms of leaf pairs. Pots were arranged in a randomized complete block design with three replications. Each herbicide that was tested represented a separate experiment, and each herbicide rate constituted a treatment. Each experiment was performed at two stages of leaf growth: one to two leaf-pairs and three to four leaf-pairs.

Herbicides tested were desmedipham plus phenmedipham (commercial premixed formulation) and imazamethabenz. They were applied in a cabinet sprayer equipped with a single flat-fan nozzle that delivered 187 L ha^{-1} at 140 kPa. Both were tested at 0, 0.01, 0.1, 0.5, 1, and 10× rates. The 1× rates were 0.36 + 0.36 for desmedipham plus phenmedipham, and 0.44 kg ai ha^{-1} for imazamethabenz (plus nonionic surfactant at 0.25% v/v). The control treatment (0×) received only water. At 2 wk after treatment (WAT), plants were assessed for injury symptoms (stunting, chlorosis, and necrosis) relative to control plants (0 = no injury, 10 = dead). The plants were clipped at soil level and aboveground fresh weights determined. Log-logistic dose response curves (Seefeldt et al. 1995) based on fresh weights were developed with the user-specified iterative procedure available in Statistix 9 software (Analytical Software. Tallahassee, FL).

Field Testing. A preliminary field study commenced in 2008 as a cursory examination of calendula response to imazamethabenz. The experiment was performed at the Swan Lake Research Farm, Stevens County (45°44′N, 95°49′W). Soil at this site was a Barnes loam (Calcic Hapludoll, fine loamy, mixed, superactive, frigid; 3.5% organic matter, pH 6.5). The previous crop was soybean. The field was fertilized with N–P–K at 70–30–30 kg ha^{-1} before sowing Carola seeds 1 to 2 cm deep at 9 kg ha^{-1} in rows separated by 25 cm. Plots were 3.1 by 6.1 m and treatments were arranged in a randomized complete block design with four replications. All plots were hand-weeded. Treatments comprised herbicide rates and a control that received no herbicides. Herbicide rates were 0.11, 0.22, and 0.44 kg ai ha^{-1} (plus 0.25% v/v surfactant). These were applied through a 3-m-wide hand-held boom mounted with six flat-fan nozzles at 207 kPa and delivering a volume equivalent to 187 L ha^{-1}. Applications occurred (Table 1) when calendula plants were at the four–leaf-pair stage of growth. Injury ratings (0 = no effect, 10 = dead), and stand densities were recorded 2 WAT, and crop biomass was harvested in two 1-m row lengths in each plot at the end of the growing season (Table 1). Biomass samples were dried at 40 C for more than 7 d and then weighed.

The study was repeated during 2009 and 2010 in commercial calendula fields in McCauleyville Township, Wilkin County, MN (46°26′N, 96°41′W), but included rates of desmedipham + phenmedipham in addition to those of imazamethabenz. In 2009, the soil was a silt loam (eroded B horizon) of a Glyndon very fine sandy loam (Aeric Calciaquoll, coarse-silty, mixed, superactive, frigid; 1% organic matter, pH 7.5). In 2010, the experiment was in a nearby field where the soil was a Doran clay loam (Aquic Argiboroll, fine, smectitic, frigid; 6% organic matter, pH 7.5). Previous crops were soybean. Fields were fertilized with N–P–K at 70–30–30 kg ha^{-1} before seeding Carola seeds 1 to 2 cm deep in rows separated by 25 cm.

Herbicide rates were 0.09 + 0.09, 0.18 + 0.18, and 0.36 + 0.36 kg ai ha^{-1} for desmedipham plus phenmedipham and 0.11, 0.22, and 0.44 kg ai ha^{-1} plus 0.25% v/v surfactant for imazamethabenz. These subsequently will be referenced as low, medium, and high rates, respectively. A no-herbicide

Table 1. Dates of agronomic operations at two sites in western Minnesota for examining calendula tolerances to POST-applied herbicides. (n/a, not applicable).

Site	Swan Lake	McCauleyville	
Year	2008	2009	2010
Seeding	May 21	June 12	July 9
POST	June 17	July 9	July 28
Evaluation	June 30	July 31	August 12
Seed harvest	n/a	September 28	November 4

control treatment also was included. Plots were 3.1 by 6.1 m and treatments were arranged in a randomized complete block design with three replications. All plots were hand-weeded. Injury evaluations, stand densities, and heights of representative plants in each plot were recorded 6 to 8 WAT rather than 2 WAT, as the additional time allowed recovery of plants from ephemeral injury caused by desmedipham plus phenmedipham treatments.

When about 60 to 80% of capitula were brown (Froment et al. 2003), diquat was applied at 1 kg ai ha^{-1} to desiccate the plants in 2009. Seeds were harvested 10 d later with a plot combine in a 1.5-m-wide swath in the middle of each plot. Seed samples were dried at 40 C for at least 7 d, cleaned, and then weighed. Because of the very late planting in 2010, plants continued to flower and mature until the first killing frost in early November. At that time, all capitula were hand-harvested within a 1 by 2–m quadrat centrally located in each plot, dried at 40 C for at least 7 d, and then threshed. Seeds subsequently were cleaned and weighed.

Prior to analyses, injury values were arcsine square-root transformed to normalize variances within treatments. Because plant responses within herbicide treatments often were not related to herbicide rate in a consistent manner, ANOVA (Statistix 9 software) was used to compare means across herbicides rather than regression.

Results and Discussion

Greenhouse Testing. Imazamethabenz applied at either one–leaf-pair or four–leaf-pair stages caused no noticeable injury to plants at the 1× rate, and fresh weights were affected marginally if at all by this rate. In contrast, 10× rates of imazamethabenz noticeably damaged plants (Figure 1). The mixture of desmedipham plus phenmedipham applied at the one– to two–leaf-pair stage killed calendula seedlings. However, when the 1× rate of desmedipham plus phenmedipham was applied at the three– to four–leaf-pair stage, older leaves were injured, but plants began recovering and producing new green leaves by 2 WAT (Figure 1).

Field Testing. Imazamethabenz, which was tested in 2008, 2009, and 2010, never injured calendula significantly at any rate or in any year ($P > 0.10$). Imazamethabenz also did not affect plant heights or crop stands ($P > 0.10$) in any year, nor aboveground biomass ($P = 0.63$), which averaged 6882 ± 398 kg ha^{-1} in 2008, the sole year in which it was measured.

Both imazamethabenz and desmedipham plus phenmedipham were examined for effects on injury and seed yield in 2009 and 2010. Unlike imazamethabenz, desmedipham plus

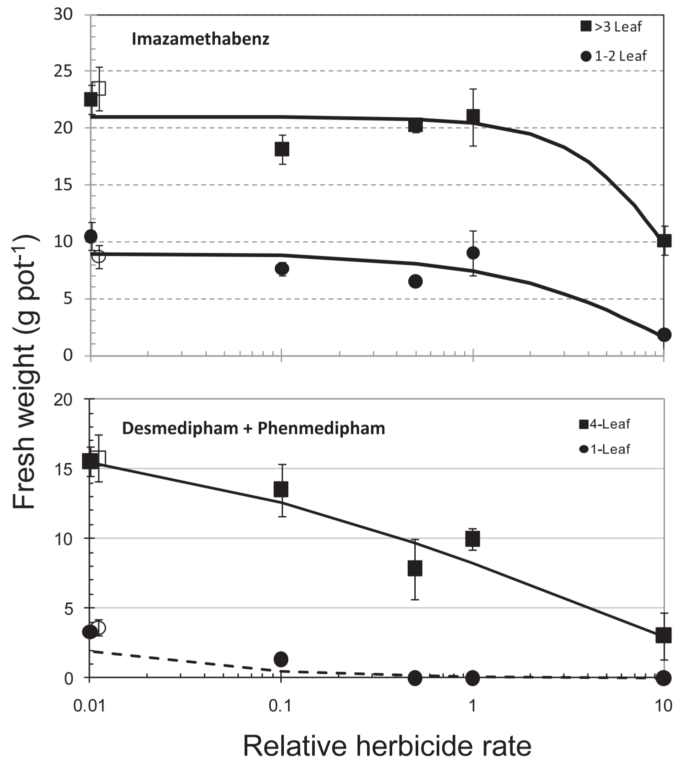

Figure 1. Dose responses of calendula to imazamethabenz and desmedipham plus phenmedipham. Open symbols represent values for controls (no herbicide). Vertical bars represent standard errors. Herbicides were sprayed at differing stages of growth: one– and four–leaf-pairs for imazamethabenz, and one to two–leaf-pairs and three to fourleaf-pairs for desmedipham plus phenmedipham. A relative herbicide rate of 1 represents 0.44 kg ai ha^{-1} for imazamethabenz and 0.36 + 0.36 kg ai ha^{-1} for desmedipham plus phenmedipham.

phenmedipham clearly damaged older leaves soon after application. However, by 6 to 8 WAT plants had recovered and injury was no longer apparent in either year ($P > 0.17$). Neither herbicide at any rate affected seed yield ($P > 0.35$), with yields averaging 1,486 ± 96 kg ha^{-1} in 2009 and 462 ± 35 kg ha^{-1} in 2010 (Figure 2). The low seed yields in 2010 reflected the very late planting date that year. Plant heights

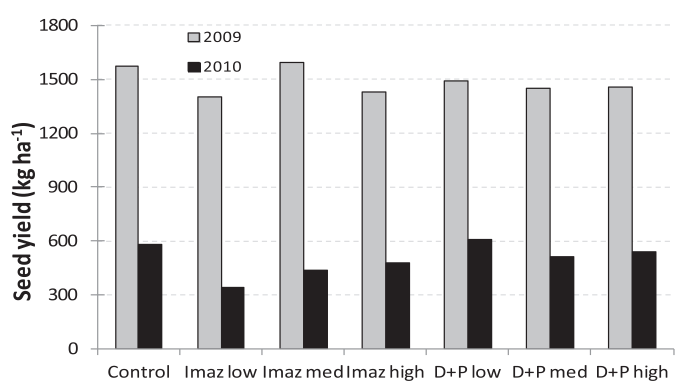

Figure 2. Seed yields of calendula after treatment with imazamethabenz or desmedipham plus phenmedipham in field experiments in 2009 and 2010. Means and standard errors (vertical bars) are displayed. No statistical differences (ANOVA) between treated and control plants were detected ($P \geq 0.35$).

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and crop stands also were not affected by herbicides or rates ($P > 0.10$). These results suggest that imazamethabenz can be applied safely to calendula at rates up to 0.44 kg ha^{-1}, and that once plants attain four pairs of leaves, the commercial tank mix of desmedipham plus phenmedipham can be applied at rates up to 0.36 + 0.36 kg ha^{-1}. However, with this latter herbicide severe leaf damage is to be expected immediately after application (typically in spring), but the plants should recover fully by 6 to 8 WAT (typically by midsummer).

Although calendula appears to tolerate POST applications of imazamethabenz completely, this herbicide unfortunately controls very few broadleaf weeds (Zollinger et al. 2010). For instance, among common broadleaf weeds in the north-central United States, only species of mustards (Brassicaceae) are controlled well by imazamethabenz. It merely suppresses species within the genera of *Kochia*, *Polygonum*, and *Salsola*. Fortunately, the commercial formulation of desmedipham plus phenmedipham compensates for this narrow spectrum of POST control, as it has high efficacy on many additional and important broadleaf species (especially *Amaranthus* spp. and *Chenopodium* spp.), which are common in temperate regions where calendula is expected to be grown. As with phenmedipham alone (Cromack and Smith 1998), desmedipham plus phenmedipham will injure young calendula seedlings and only can be used on plants at or beyond the four-leaf pair stage of growth.

In summary, the two POST-applied herbicides identified as useful in calendula are readily available and used for other crops in the north-central United States. Furthermore, these herbicides control a spectrum of weed species that is sufficiently broad to permit most prospective growers in northern regions to plant calendula with a reduced fear of incurring large infestations of escaped weeds. However, neither herbicide currently (2012) is registered for use in calendula.

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