Effect of Timing and Rates of Application of Glyphosate and Carfentrazone Herbicides and Their Mixtures on the Control of Some Broadleaf Weeds

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Additional index words. weed control, ivyleaf morning-glory, *Ipomea hederacea*, milkweed vine, *Morrenia odorata*, hemp sesbania, *Sesbania exaltata*, field bindweed, *Convolvulus arvensis*, glyphosate, carfentrazone

Abstract. Greenhouse and field trials were carried out to evaluate carfentrazone as a potential tank mix with glyphosate to control weeds. Application of active ingredient glyphosate at 1.15 kg·ha⁻¹ provided 44%, 50%, 19%, and 17% control of ivyleaf morning-glory, milkweed vine, hemp sesbania, and field-bind weed (stage 1), respectively, and increased to 45%, 51%, 31%, and 76%, respectively, with active ingredient of 2.30 kg·ha⁻¹. Carfentrazone as active ingredient at 17.7 g·ha⁻¹ achieved 53%, 90%, and 99% control of hemp sesbania, ivyleaf morning-glory, and milkweed vine (stage 1), and increased to 88%, 98% in first two weed plants, respectively, with active ingredient at 52.2 g·ha⁻¹. Either rate of carfentrazone at any stages of field-bind weed yielded ≈100% control. Application of tank-mixed glyphosate and carfentrazone to ivyleaf morning-glory and hemp sesbania (stage 1) demonstrated greater control than their sole applications. A complete control of milkweed vine and field-bind weed (stage 1) was achieved by tank-mixed glyphosate and carfentrazone. Corresponding to percent control values a reduction in biomass value was also recorded. Biomass reduction with glyphosate at either stage of ivyleaf morning-glory was only 14%–24% and reduction with carfentrazone was 40%–47%. Biomass was further reduced with the tank-mixed glyphosate and carfentrazone. A similarly trend in biomass reduction was noted in milkweed vine and hemp sesbania. However, ivyleaf morning-glory was found to be the most tolerant weed to glyphosate followed by hemp sesbania, milkweed vine, and field-bind weed. Tank-mixed applications of these two herbicides further increased the percent control and biomass reduction. In all weed species, there was a significant decrease in percent biomass reduction with age. Although the types of weed were different in the field experiment and greenhouse, a similar trend was observed in the percent control achieved with glyphosate, carfentrazone, and their tank-mixed application. Tank-mixed applications achieved 93%–95% control of Brazil pusley and 75%–83% control of passion flower. These values were significantly higher than the percent control achieved with application of only glyphosate. Therefore, tank-mixed application of glyphosate and carfentrazone may be beneficial than sole application to control broadleaf weeds.

Several factors influence the efficacy of foliar applied herbicide, e.g., water quality, adjuvant, tank-mixed application of two or more herbicides, and environmental conditions (Colby, 1967; Foy, 1989; McWhorter, 1982). Adjuvants often improve efficacy of foliar applied herbicides (Hart and Wax, 1996; Sharma and Singh, 1999). When two or more herbicides are tank-mixed and applied together and the resulting effect is greater than the expected control of the individual herbicides applied alone, the combination is said to be synergistic (Colby,

1967). However, a tank-mixed application could also result in reduced control under certain circumstances; such combinations are said to be antagonistic.

Glyphosate has been used for vegetation management in citrus groves and is the most commonly used herbicide for effective post-emergence (POST) weed management in the Florida (Jackson and Davies, 1999). Although glyphosate is a broad-spectrum herbicide, not all weeds are equally susceptible (Culpepper and York, 2000; Payne and Oliver, 2000). Taylor (1996) reported that some grasses, such as barnyardgrass (*Echinochloa crus-galli*) and broadleaf signalgrass (*Brachiaria platyphylla*), are more sensitive to glyphosate than broadleaf species, such as velvetleaf (*Abutilon theophrasti*) and morning-glory. These differences in susceptibility

to glyphosate may be attributed to lower absorption of glyphosate due to physico-chemical differences in the plant cuticle and reduced translocation from the treated leaf (Taylor, 1996). Pitted morning-glory is among the most troublesome and common weed species found in roadsides, fence rows, noncrop areas, pastures, and utility poles (Anonymous 2000, 2001; Uva et al., 1997). Norsworthy et al. (2001) reported only 59% and 69% control of 3- to 4-leaf pitted morning-glory using glyphosate as active ingredient at 0.85 and 1.25 kg·ha⁻¹, respectively, compared with at least 98% control of more sensitive weeds, such as barnyardgrass [*Echinochloa crus-galli* (L.)] and prickly sida (*Sida spinosa* L.).

Reduced efficacy of glyphosate on some weed species has been instrumental in their increased infestation due to its continuous use in many groves. It has been observed that several broadleaf weeds have less phytotoxic effect/control by glyphosate application (Singh and Singh, 2005). For example, Brazil pusley (*Richardia brasiliensis*) is a problematic weed in Florida citrus plantations, and effective doses of glyphosate do not provide adequate control of various weeds, including Brazil pusley (personal observation). Carfentrazone-ethyl has been found effective against certain broadleaf weeds but has no activity on grasses (Vencill, 2002). Carfentrazone-ethyl inhibits the protoporphyrinogen oxidase enzyme and therefore provides control of selected broadleaf weeds, including kochia (Dayan et al., 1997). Observed symptoms of carfentrazone-ethyl treatments are a rapid necrosis of plant tissues. This fast activity makes carfentrazone an ideal candidate for postemergence and burn-down applications (Mize et al., 2002). Carfentrazone-ethyl applied at recommended growth stages provided 99% control of kochia (*Kochia scoparia* [L.]), including resistant biotypes (Nandula and Manthey, 2002). Thus carfentrazone-ethyl is a relatively new broadleaf herbicide in the phenyl triazolinone class of chemicals (Dayan et al., 1997). Alternate methods, such as tank-mixed application, may provide improved weed control under various cropping systems. No single herbicide can provide adequate control of all the weed species, even in herbicide-tolerant (e.g., Roundup-Ready) crops. Herbicide mixtures application may be beneficial for better weed management. Scanty research has been conducted to evaluate the potential of carfentrazone as a tank-mixed partner with glyphosate. Therefore, the objective of the study was to evaluate carfentrazone as a potential tank-mixed partner for glyphosate to improve the control of hard-to-control weeds. The study was conducted in greenhouse as well as in the field.

MATERIALS AND METHODS

Greenhouse study

Plant material. Four weed species—field bindweed (*Convolvulus arvensis*), hemp sesbania (*Sesbania exaltata*), milkweed vine

Received for publication 16 Jan. 2007. Accepted for publication 1 Apr. 2007.

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(*Morrenia odorata*), and ivyleaf morning-glory (*Ipomoea hederacea*)—were grown in an environment controlled greenhouse maintained at day/night temperature of 25/16 °C (± 0.5 °C), 70% ($\pm 5\%$) relative humidity, and daylight. The greenhouse reduced the photosynthetically active radiation (PAR) to a maximum of 1200 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at midday. The selected weed species seeds (Valley Seed, Fresno, CA) were sown in potting medium (Fafard Professional 4 Mix Formula, Conrad Fafard, Agawam, MA) on 14 Nov. 2005 and for repeated study on 21 Dec. 2005. Herbicide treatments were applied at three different stages of weed growth: at stage 1 (3 weeks; ivyleaf morning-glory = 15 cm, milkweed vine 10 cm, hemp sesbania = 17–20 cm, field-bind weed = 17–20 cm), at stage 2 (5 weeks; ivyleaf morning-glory = 30 cm, milkweed vine = 17–20 cm, hemp sesbania = 35 cm, field-bind weed = 30 cm), and at stage 3 (7 weeks; ivyleaf morning-glory = 35–40 cm, milkweed vine = 20–25 cm, hemp sesbania = 40–45 cm, field-bind weed = 40–45 cm) after sowing of seeds in plastic trays/pots. The plants treated at stages 1 and 2 were grown in 72-hole (2.5 cm $\times$ 7.5 cm) plastic trays, and those treated at stage 3 were grown in 15 $\times$ 10 cm plastic pots. All plastic trays and pots were fertilized with a 20N–20P–20K fertilizer (Helena Chemical Co., Collierville, TN) 2 weeks after sowing and before treatment.

Efficacy measurement. The treatments applied were, glyphosate as Credit (isopropylamine salt, 480 g·L⁻¹) at 1.25 and 2.5 kg·ha⁻¹ (Nufarm, Burr Ridge, IL), carfentrazone as Aim EC (2.0 lb/gal) at 17.5, 35.0, and 52.5 g/ha (FMC Corporation, Philadelphia, PA), and glyphosate at 1.25 kg/ha tank-mixed with carfentrazone at 17.5 and 35.0 g·ha⁻¹. The treatment solutions were prepared immediately before use and applied using a Chamber Track Sprayer (Allen Machine Works, Midland, MI). The sprayer was fitted with Teejet 8003 flat fan spray nozzles (Spraying System Co., Wheaton, IL) delivering 189 L·ha⁻¹ at 22 psi pressure. After spraying, the experimental trays/pots were returned to the greenhouse conditions as stated above. The plastic trays/pots were watered daily to avoid water stress.

Above-ground biomass of each species was harvested 14 d after treatment (DAT) application, oven-dried at 40 °C for 14 d, then weighed and presented as dry weight in gm. Percent injury to growing weed seedlings for each weed species was also assessed at 14 DAT. A scale of 0 to 100 was used; 0 indicating no damage and 100 indicating complete damage as approved by the Weed Science Society of America (Frans et al., 1986).

Field study

The field experiment was conducted at the University of Florida, Citrus Research and Education Center's Riley block citrus grove in Haines City. The broadleaf weed species growing under the tree or in tree rows were hairy indigo (*Indigofera hirsuta*), Brazil pusley (*R. braziliensis*), and maypop passionflower (*Passiflora incarnata*). The only

grass present in the treated plots was natal-grass (*Melinis repens*). All plots were infested with Brazil pusley and hairy indigo; maypop passionflower plants were present in majority of the plots. Spotted spurge (*Euphorbia maculata*) and hyssop spurge (*Euphorbia hyssopifolia*) plants were present only in some experimental plots. Herbicide treatments viz. glyphosate as Credit at 1.25 and 2.5 kg/ha, carfentrazone as Aim EC at 17.5 and 35.0 g·ha⁻¹, and glyphosate at 1.25 kg·ha⁻¹ tank-mixed with both rates of carfentrazone were applied. Solutions of nonionic surfactant X-77 were freshly prepared and separately incorporated at 0.25% v/v with all

the treatments except glyphosate at 2.5 kg/ha to examine the effect on efficacy of the treatments. Surfactant X-77 is a mixture of alkylaryl polyoxyethylene glycols and is widely used as a surfactant in herbicide applications. Herbicide treatments were sprayed using a tractor mounted sprayer fitted with 80015 Teejet nozzles and an off-center OC-03 flat spray tip toward the tree row, delivering 189 L·ha⁻¹ volumes of water at 1.5 bars pressure. The soil at the experimental site was Florida Candler fine sand. The treatments were applied on 9 Nov. 2005. There was no rain after application of treatments. The plot size was 3.05 $\times$ 18.3 m.

Fig. 1. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent control of ivyleaf morning-glory (Overall LSD = 10.0).

Note: In all figures (1 to 9): stage 1 (3 wk; ivyleaf morning-glory = 6 in, milkweed vine 4 in, hemp sesbania = 7–8 in, field-bind weed = 7–8 in), stage 2 (5 wk; ivyleaf morning-glory = 12 in, milkweed vine 7–8 in, hemp sesbania = 14 in, field-bind weed = 12 in), and stage 3 (7 wk; ivyleaf morning-glory = 14–16 in, milkweed vine = 8–10 in, hemp sesbania = 16–18 in, field-bind weed = 16–18 in); Gly 1, 2 = glyphosate 1.25 kg·ha⁻¹, 2.5 kg·ha⁻¹; CFN 1, 2, 3 = carfentrazone 17.5, 35, 52.5 g·ha⁻¹; Gly + CFN = tank mixed glyphosate and carfentrazone.

Fig. 2. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent control of milkweed vine (Overall LSD = 16.0).

After treatment, weekly visual observations of phytotoxic effects were recorded as percent control of weeds using a 4-week period after treatment (WAT). The rating scale was 0 to 100, with 0 implying no control and 100 implying complete control of the weed plants, as approved by the Weed Science Society of America (WSSA; Frans et al., 1986).

Statistical analysis

Greenhouse study. Each plastic tray consisting of 72 holes contained three rows with six plants in a row of each species and three replicated trays. The weed plants grown in plastic pots had four replications, with a minimum of five plants in each pot per replication. The experiment was repeated. Data of two experiments were combined after performing a test of homogeneity of variance.

Field study. The weeds in the field experiment were analyzed separately. The experiment was designed as a randomized complete block with four replications. There were five citrus trees in each replication.

In both experimental situations, data on percentage were transformed to arc-sine values and subjected to ANOVA using the Agriculture Research Manager software (Gylling Data Management, Inc., Brookings, SD), but are presented in the original form for clarity. Means were separated using Fisher's protected least-significant difference test (LSD at $P = 0.05$). Means were separated using Fisher's protected least significant difference test (LSD at $P = 0.05$).

RESULTS AND DISCUSSION

Greenhouse study

Efficacy. Application of glyphosate at 1.25 kg/ha to 3-week-old plants provided 44%, 50%, 19%, and 17% control of ivyleaf morning-glory, milkweed vine, hemp sesbania, and field-bind weed, respectively (Fig. 1–4). The percentage control of hemp sesbania and field-bind weed was further increased to 31% and 76%, respectively, with an increase in the glyphosate rate to 2.5 kg·ha⁻¹, while control of morning-glory increased slightly from 38% to 45% and milkweed vine remained the same. The percent control was declined with increasing age in all weed species, and this reduction was significant from stage 1 to stage 3. The flowering of ivyleaf morning-glory was inhibited by the application of glyphosate at 2.5 kg·ha⁻¹. There was some suppression of growth of ivyleaf morning-glory plants, but these plants showed considerable tolerance to glyphosate application. Therefore, sublethal preflowering applications of glyphosate altered plant architecture in ivyleaf morning-glory. During vegetative growth phases, glyphosate accumulated in regions of meristematic growth (Pline et al., 2001; Sandberg et al., 1980). In addition, glyphosate inhibits the production of tryptophan, a precursor to indoleacetic acid (IAA) (Gruys and Sikorski, 1999).

Because of accumulation of glyphosate and inhibition of IAA, sublethal glyphosate rates can cause death of the apical meristem, consequently releasing apical dominance, allowing production of lateral branches. These symptoms appeared in ivyleaf morning-glory in this study with the application of glyphosate. Koger et al. (2004, Koger and Reddy, 2005) concluded that inadequate control of pitted morning-glory was related to sublethal glyphosate rate. Thomas et al. (2005) also reported that glyphosate applied at 12 leaf stage (L) and sequential application at 4 and 8 L averaged over glyphosate rates, reduced cumulative flower production after 8 weeks by 65% and 54%, respectively.

Application of carfentrazone at 17.5 g·ha⁻¹ achieved 90% control of stage 1 ivyleaf morning-glory, which increased to 98% at 52.5 g·ha⁻¹. There was a significant reduction in control with increasing age of ivyleaf morning-glory with either rate of carfentrazone. However, control of 7-week-old ivyleaf morning-glory was >76% with 17.5 g·ha⁻¹ carfentrazone. Similar results were reported by Wyatt et al. (2005) for entire-leaf morning-glory. Control of hemp sesbania was only 53% with carfentrazone at 17.5 g·ha⁻¹, and control increased to 88% with carfentrazone at 52.5 g·ha⁻¹. With increase in the age of hemp sesbania, percent control by carfentrazone was significantly reduced. Similarly,

Fig. 3. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent control of hemp sesbania (Overall LSD = 16.0).

Fig. 4. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent control of field-bind weed (Overall LSD = 6.8).

control of milkweed vine was significantly reduced from 99% to 47%, 98% to 63%, and 99% to 69% with 17.5 to 52.5 g·ha⁻¹ carfentrazone, respectively, due to the increase in age of plants. In contrast, the control of field-bind weed was ≈100% with application of either rate of carfentrazone at all the stages. Likewise, Nandula and Manthey (2002) also reported adequate to excellent control of resistant kochia inbreds with postemergence-treated carfentrazone and several other herbicides. In this connection, control of broadleaf weeds by carfentrazone has been reported by several researchers (Buker et al., 2004; Ellis and Talbert 2004).

There was an increase in the percent control of ivyleaf morning-glory and hemp sesbania with tank-mixed application of glyphosate with two rates of carfentrazone, although it was not significant at stage 1 as compared with carfentrazone alone. Similar to the individual application of glyphosate and carfentrazone, the percent control of ivyleaf morning-glory and hemp sesbania was reduced with plant age when a tank-mixed glyphosate and carfentrazone was applied. The control of milkweed vine was 100% when tank-mixed glyphosate with either rate of carfentrazone was applied at stage 1, and this control was reduced to 79%–85% when applied to stage 3 milkweed vine. The control of field-bind weed was 100% with the application of tank-mixed glyphosate with both rates of carfentrazone at all stages. Reduction in efficacy of herbicides due to increase in the age of weed plants has been documented (Singh and Singh 2004). Of the four weed species, field-bind weed was most sensitive to all the treatments applied except glyphosate at 1.25 kg·ha⁻¹, and ivyleaf morning-glory was the most tolerant species.

Biomass reduction. Ivyleaf morning-glory exhibited resistance/tolerance to glyphosate, as evidenced from percent biomass reduction. Biomass reduction with glyphosate at both stages in ivyleaf morning-glory was only 14%–24% (Fig. 5), whereas application of carfentrazone achieved 40%–47% reduction in biomass of ivyleaf morning-glory, which was increased further with tank-mixed glyphosate and carfentrazone. Biomass reduction was less at stages 2 and 3 as compared with stage 1 plants of ivyleaf morning-glory.

Similarly, with milkweed vine, the percent reduction in biomass was more at stage 1 than at stages 2 and 3 (Fig. 6). There was no significant difference in percent reduction in biomass among any treatment applied at stage 3 milkweed vine. Reduction in biomass of hemp sesbania was 22%–26% with glyphosate at stage 1 and 52%–69% with carfentrazone and was further increased with the tank-mixed application of glyphosate and carfentrazone (Fig. 7). This increase in biomass reduction in hemp sesbania was significantly higher than application of glyphosate alone. In general, among all test plants, percent reduction in biomass decreased with the increase in age. Reduction in biomass was significantly higher with tank-mixed applica-

tion of glyphosate and carfentrazone than the individual application of glyphosate or carfentrazone. Percent reduction in biomass demonstrated a similar trend in field-bind weed (Fig. 8) as observed in hemp sesbania (Fig. 7).

Field study.

Brazil pusley, hairy indigo, passion-flower, garden spurge, and natalgrass were present in the experimental grove. Application of glyphosate at 1.25–2.5 kg·ha⁻¹ achieved 64%–76% control of Brazil pusley, 100% of hairy indigo, spurge, and natalgrass, but only 45%–56% control of passion-flower was recorded (Fig. 9). Application of carfentrazone at 17.5 and 35.0 g·ha⁻¹ obtained only 28%–33% control of Brazil pusley, 73%–78% control of hairy indigo, 60%–70% control of passion-flower, and 69%–75%

control of garden spurge, and there was no effect on natalgrass. Tank-mixed application of glyphosate and carfentrazone provided 93%–95% control of Brazil pusley and 75%–83% control of passion-flower, which was significantly higher than the percent control achieved with the sole application of glyphosate. There was no significant difference in the percent control of hairy indigo and garden spurge recorded, either with a sole application of glyphosate or tank-mixed with carfentrazone. Singh and Singh (2005) did not record any synergistic effect of tank-mixed application of glyphosate and carfentrazone on Brazil pusley in a field study. Addition of surfactant to glyphosate enhanced the percent control values (Sharma and Singh, 1999). Norsworthy and Grey (2004) reported that there would be no benefit from nonionic surfactant addition to

Fig. 5. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent reduction in biomass of ivyleaf morning-glory (Overall LSD = 7.9).

Fig. 6. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent reduction in biomass of milkweed vine (Overall LSD = 5.6).

Fig. 7. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent reduction in biomass of hemp sesbania (Overall LSD = 12.4).

Fig. 8. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent reduction in biomass of field-bind weed (Overall LSD = 14.2).

Fig. 9. Effect of timing and rates of application of glyphosate, carfentrazone, and their tank mixtures on percent control of weed in citrus grove [LSD P (0.05) = Brazil pusley 6.5, hairy indigo 7.8, passion flower 8.3, garden spurge 7.6 and natalgrass 0].

glyphosate formulation when combined with chlorimuron. There was no significant difference between the herbicide treatments applied with or without surfactant.

In this study, based on control and biomass reduction, it was found that ivyleaf morning-glory was the most tolerant weed followed by hemp sesbania, milkweed vine, and field-bind weed. Glyphosate and carfentrazone showed an additive effect when tank-mixed and increased control and reduced biomass more than the individual application of carfentrazone. Additional data indicated that increasing the age of the weed plants decreased the control and reduction in biomass accumulation. Although the weeds were different in the field experiment and greenhouse, similar trends were observed in the percent control of broadleaf weeds by glyphosate, carfentrazone, and their tank-mixed application. Tank-mixed applications provided 93%–95% control of Brazil pusley and 75%–83% control of passion flower. These values were significantly higher than the percent control achieved than application of glyphosate alone. Therefore, tank-mixed application of glyphosate and carfentrazone may be beneficial to citrus growers in controlling broadleaf weeds. Future study may be targeted at the grove having difficult-to-control weeds, e.g., Spanishneedles, Brazil pusley, dayflower, passion flower, etc. This study will further add to the information that tank-mixed application of carfentrazone and glyphosate may be better in controlling a broad spectrum of weeds.

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