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Efficacy of tembotrione on grass species as influenced by herbicides and adjuvants

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EFFICACY OF TEMBOTRIONE ON GRASS SPECIES AS INFLUENCED BY HERBICIDES AND ADJUVANTS

By

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Field and greenhouse experiments were conducted at Southern Illinois University-Carbondale in 2006 and 2007 to evaluate the herbicide tembotrione for postemergence grass control. Tembotrione inhibits the p-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, which aids in the formation of essential plant constituents for photosynthesis. Tembotrione efficacy was examined in the greenhouse on large crabgrass, giant foxtail, shattercane, and fall panicum. Significant activity that could translate to commercial levels of weed control in the field was found on all species except fall panicum. Greenhouse studies also compared the efficacy of tembotrione, mesotrione, and topramezone which represent the three HPPD-inhibiting herbicides commercially available in U.S. corn production. Tembotrione and topramezone have more activity on these grasses than mesotrione. Tembotrione was also tank-mixed with either nicosulfuron or foramsulfuron to evaluate fall panicum response. Activity on fall panicum was similar weather nicosulfuron or foramsulfuron was applied alone or with tembotrione. In the field, it was also determined that nicosulfuron or foramsulfuron could be added to tembotrione to control fall panicum. The addition of atrazine to nicosulfuron and tembotrione did not negatively effect fall panicum control. It was also observed in both the field and greenhouse that utilizing methylated seed oil provided more activity than crop oil concentrate.

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CHAPTER 1

LITERATURE REVIEW

Many factors bring about the need for a company to invest resources into new herbicides including: potential market share, market competition strength, commodity shifts, and weeds resistant to herbicides (Tranel et al. 2002). With over 97% of the corn (*Zea mays*) hectares in the United States receiving at least one herbicide application per growing season (USDA 2005), the need for new herbicide active ingredients and modes of action are evident as herbicide-resistant weed species become more prominent. New modes-of-action for herbicides are desired to control weeds that have developed resistance to older and more widely used chemical families (Heap 1997). In corn production, new herbicide active ingredients are of great importance because of the wide use of atrazine, a photosystem II inhibitor, and the resistance many weed species have shown to photosystem II inhibitors. Resistance to one mode of action is troublesome, but continued use of certain herbicides can result in weeds becoming resistant to two or even three herbicide modes-of-action (Legleiter 2008). Throughout the world the majority of weed biotypes showing resistance to three herbicide modes of action are grasses. This is interesting since often times the most troublesome weed species for corn producers are grasses (Patzoldt et al. 2005).

HPPD-Inhibiting Herbicides

The most recent herbicide chemical families being developed inhibit the *p*-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme (Lee et al. 1997). The HPPD enzyme aids in the formation of plastoquinone (PQ) and α-tocopherol. The PQ is a necessary cofactor for phytoene desaturase, an enzyme used further in the production of carotenoids. Without carotenoids, chlorophyll is not protected from radicals created by ultraviolet light. Thus, inhibition of the HPPD enzyme will indirectly cause bleaching symptoms of leaf tissue from the degradation of chlorophyll (Lee et al. 1997). HPPD-inhibiting herbicides recently commercialized include; isoxaflutole (Pallett 1998), mesotrione (Mitchell 2001), topramezone (Porter et al. 2005), and tembotrione (Hinz et al. 2005).

Applications of isoxaflutole to sensitive plant species will show bleaching of new leaves followed by growth suppression and necrosis resulting in plant death in species that are susceptible (Viviani et al. 1998). The difference in tolerant and susceptible plant species is the ability of tolerant plants to convert the active diketonitrile into the inactive benzoic acid (Pallett et al. 1998). The rate at which isoxaflutole is converted to benzoic acid is how corn can tolerate isoxaflutole applications whereas slower conversion in susceptible weeds results in plant death. Isoxaflutole is a member of the isoxazole family and is used preemergence or early preplant at 75 to 140 g ai/ha (Senseman 2007). Isoxaflutole controls a variety of grass and broadleaf weeds including; barnyardgrass, large crabgrass, velvetleaf, yellow foxtail, and common lambsquarters (Bhowmik et al. 1999).

Topramezone has more recently received registration for use in corn and is used for postemergence applications at rates of 12 and 18 g ai/ha (Porter et al. 2005). Previous research with topramezone has shown effective control of major broadleaf weeds as well as several grass species (Porter et al. 2005).

Mesotrione is another widely used HPPD inhibitor and can be used preemergence or postemergence in corn (Anonymous 2005). Discovery of this compound came from observations from the *Callistemon citrinus* or the California bottlebrush plant. It was noted that few other plant species grew near the bottlebrush plant and extractions from the soil near bottlebrush revealed the herbicidal compound leptospermone, an allelochemical, was being excreted from the *C. citrinus* (Mitchell et al. 2001). Postemergence control of primarily broadleaf species can be achieved with mesotrione at a common rate of 105 g ai/ha (Bollman 2006). Mesotrione has been shown to control *Xanthium strumarium* (common cocklebur), *Abutilon theophrasti* (velvetleaf), *Ambrosia trifida* (giant ragweed), as well as *Chenopodium*, *Amaranthus,* and *Polygonum* species. Mesotrione has exhibited good crop tolerance with no corn injury being observed preemergence in some research, and less than 3% injury to corn in postemergence applications (Mitchell et al. 2001). The reason for this lack of injury in corn and control of weed species is rate of metabolism as corn can rapidly metabolize mesotrione (Mitchell et al. 2001).

The newest HPPD-inhibiting herbicide is tembotrione which has activity similar to topramezone in that postemergence applications of tembotrione at 92 g ai/ha has activity on a variety of broadleaf and grass weed species (Hinz et al. 2005). Tembotrione was first commercialized in the U.S. for weed management in corn in 2008. In contrast to other HPPD-inhibiting herbicides, selectivity in corn requires the use of a chemical safener that promotes faster metabolism of tembotrione in corn. The safener, isoxadifen, is formulated in the same product with tembotrione in a 2:1 ratio of tembotrione:isoxadifen. Tembotrione applications with isoxadifen have resulted in excellent crop safety showing minimal crop injury at three-times the proposed use rate (Hinz et al. 2005). Even though postemergence applications of tembotrione can control a wide spectrum of grass and broadleaf weeds, some significant differences in weed species sensitivity to tembotrione are evident. In particular, some grass weed species which are problematic for corn producers have been controlled to varying degrees with tembotrione with one of the least sensitive grass species being fall panicum (Hinz et al. 2005).

Fall panicum is a native warm season summer annual grass species with usually no hairs on the leaf surface or leaf sheaths, a hairy ligule, and a prominent midrib, noticeably white in color (Stubbendieck et al. 1995). Fall panicum can be found in full or partial sunlight, prefers moist, fertile loam soils, and has been collected in most counties in Illinois, as well as 95% of the United States (USDA 2007).

Factors that Influence Foliar Herbicide Efficacy

Herbicide combinations. Applicators will frequently combine two herbicides in a single application to reduce labor and other costs associated with separate applications. This practice is known as tank-mixing since the herbicides are added together in the spray tank solution. Often mesotrione has been tank-mixed with herbicides for improved control of grass species (Armel et al. 2003a). Nicosulfuron and foramsulfuron are two sulfonylurea herbicides that have shown excellent grass control and may prove beneficial in tank-mixtures with new HPPD-inhibiting herbicides. Mesotrione does not control giant foxtail or fall panicum (Anonymous 2005), however, foramsulfuron can control both of these species (Anonymous 2005a). Foramsulfuron in combination with mesotrione has shown similar response in giant foxtail and fall panicum control, and increased broadleaf control compared with foramsulfuron alone (Bunting et al. 2005). Antagonism is when two herbicides are tank-mixed and the resulting efficacy is less than the control obtained from one of the herbicides applied alone. Combining mesotrione to foramsulfuron or nicosulfuron on some grass species have been antagonistic compared with foramsulfuron or nicosulfuron applied alone (Schuster et al. 2004). This antagonism was directly related to the rate of mesotrione; meaning lower rates of mesotrione resulted in less antagonism (Schuster et al. 2004). Dobbles and Kapusta (1993) have shown significant reductions in giant foxtail control when atrazine was added to nicosulfuron. Reductions in giant foxtail and fall panicum control have also been observed when atrazine was added to foramsulfuron, depending on the adjuvant used (Bunting et al. 2005).

Atrazine is a widely used herbicide in field corn (USDA 2005) for control of many weeds and has been used in tank-mix combinations to increase weed control (Johnson 2002). Synergism is the exact opposite of antagonism, in that when two or more herbicides are tank-mixed the resulting efficacy is greater than the control obtained from the herbicides applied alone. Synergistic interactions have been observed when atrazine was combined with HPPD-inhibitors (Abendroth et al. 2006). Atrazine inhibits the D1, quinone-binding protein blocking electron transport in photosystem II of photosynthesis (Duke 1990). Topramezone is suggested to be used with atrazine to optimize weed control in folair applications. Relatively lower rates of atrazine can be applied with topramezone for control of weeds present at application, and higher rates are suggested for added residual control of weeds that may emerge (Anonymous 2005). Creech et al. (2004) demonstrated mesotrione applied postemergence has little effect on green foxtail, but the combination with atrazine resulted in effective control. The authors concluded that mesotrione and atrazine work together to attack the plants carotenoid biosynthesis and photosystem II pathways (Creech et al. 2004).

In some instances, applicators may combine three herbicides to achieve broad-spectrum weed control such as the tank-mixing an HPPD-inhibitor, a photosystem II inhibitor, and a herbicide from the sulfonylurea chemical family. Herbicide antagonism resulting in insufficient grass control has been observed with the combination of mesotrione, atrazine, and the sulfonylurea herbicides; foramsulfuron or nicosulfuron (Schuster et al. 2004). These antagonistic interactions can provide significant challenges to weed management practitioners who desire to integrate new herbicides while controlling weeds with some predictability.

Adjuvants. Adjuvants are used to enhance the activity of agri-chemicals (Hazen 2000). In addition to tank-mixing herbicides choosing proper adjuvants will aid in herbicide efficacy. The optimal adjuvant used in conjunction with certain herbicides can have great benefits for weed control (Underwood 2000). Two general categories of adjuvants are 1) adjuvants that modify the physical characteristics of the spray solution and 2) adjuvants that increase the efficacy of the chemical used in solution (Hazen 2000). Increasing the efficacy of the foliar-applied herbicide is critical for weed management and commercial success.

Either surfactants or penetrating agents are commonly used with herbicides to enhance herbicide efficacy. A surfactant is a product used to modify a solution so that it may be taken into the plant more efficiently, by reducing surface tension on the plant (Hazen 2000). A nonionic surfactant (NIS) is an adjuvant with no ionizable groups but contain both hydrophilic and lipophilic regions (Hazen 2000). Penetrating agents include crop oil concentrate (COC) and methylated seed oil (MSO). These penetrating agents are used to promote the movement of the herbicide through the major hydrophobic barriers for leaf uptake such as the epicuticular wax and perhaps the cellular membrane. Some herbicide recommendations discourage the use of MSO because they may provide too much damage to crop leaf tissue allowing excessive herbicide uptake and potential crop injury compared with crop oil concentrate. However, herbicides applied with MSO can result in weed control that is similar or greater than the same herbicide applied with crop oil concentrate (Dahl et al. 2005). A general ranking of these three types of activator adjuvants for the greatest herbicide efficacy would be MSO>COC>NIS (Young and Hart 1998).

Tembotrione, being the newest HPPD-inhibitor introduced, still has a lot of questions regarding activity. Research needs to be conducted on what species tembotrione controls and what sizes are proper for tembotrione applications. Adjuvant considerations also need to be examined with tembotrione. If there are any species that tembotrione does not control, research needs to be conducted with tank-mix partners and adjuvants to help improve weed control, but also remain safe to the crop and environment.

CHAPTER 2

EFFICACY OF TEMBOTRIONE ON GRASS SPECIES AS INFLUENCED BY HERBICIDE TANK-MIXTURES, ADJUVANT, AND WEED GROWTH STAGE

Abstract. Greenhouse studies were conducted to determine the effect of adjuvant and weed growth stage on the efficacy of tembotrione compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron. A rate titration of each herbicide (1/32 to 2X normal use rate) were applied in combination with nonionic surfactant (NIS), crop oil concentrate (COC), or methylated seed oil (MSO) at two growth stages, 2- to 3-leaf and 4- to 6-leaf large crabgrass, giant foxtail, shattercane, and fall panicum. In some instances, growth reduction of over 50% was observed even at the lowest rate tested. This occurred; on 2- to 3- leaf large crabgrass with tembotrione, on 2- to 3- leaf shattercane with the both foramsulfuron and nicosulfuron, and on 4- to 6- leaf giant foxtail with foramsulfuron or nicosulfuron when these herbicides were applied with NIS or MSO. In some instances, growth reduction of 50% was not observed even at the highest rate tested. This occurred with mesotrione on 2- to 3- leaf giant foxtail and 4- to 6- leaf fall panicum. In no instance did either adjuvant or grass growth stage influence efficacy when applied with the ALS-inhibiting herbicides. Tembotrione, topramezone, and mesotrione all had the same level of activity on 4- to 6- leaf shattercane regardless of adjuvant. No differences in 2- to 3- leaf fall panicum activity were observed when tembotrione was added to the seven rates of the ALS-inhibiting herbicides.

Nomenclature: Foramsulfuron, mesotrione, nicosulfuron, tembotrione, topramezone; large crabgrass, *Digitaria sanguinalis* (L.) DIGSA; fall panicum, *Panicum dichotomiflorum* PANDI; giant foxtail, *Setaria faberi* SETFA; shattercane, *Sorghum bicolor* (L.) SORVU.

Key words: Crop oil concentrate, herbicide interactions, methylated seed oil, nonionic surfactant, *p*-hydroxyphenylpyruvate dioxygenase (HPPD), sulfonylurea herbicides.

INTRODUCTION

Mesotrione, topramezone, (Senseman 2007) and tembotrione (Hinz et al. 2005) have all been commercialized in the past decade for postemergence weed control in corn and share the *p*-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme as a site of action. The HPPD enzyme aids in the formation of plastoquinone and α-tocopherol. Plastoquinone is a necessary cofactor for phytoene desaturase, an enzyme used further in the production of carotenoids (Lee et al. 1997). Mesotrione has activity on a variety of broadleaf weeds such as common cocklebur, velvetleaf, and giant ragweed as well as certain grass species (Mitchell et al. 2001). Topramezone controls a similar spectrum of broadleaf weeds as mesotrione, but has activity on more grass species than mesotrione (Kaastra et al. 2008). Tembotrione was the most recent HPPD-inhibiting herbicide commercialized in corn and controls several broadleaf weed species similar to mesotrione and topramezone (Bollman et al. 2008; Hinz et al. 2005).

Management of grass weeds in corn can be challenging with *Setaria* species, fall panicum, large crabgrass, and shattercane being some of the most problematic (Loux and Berry 1991) and widely distributed grass species (USDA 2007). Postemergence (POST) control of these grass species in conventional corn has typically been accomplished with the use of ALS-inhibiting herbicides (USDA 2005). However, the use of mesotrione, topramezone, and tembotrione for control of grass species has been of interest to growers who may be using these herbicides for the broadleaf weed management in the same application. Applications of these herbicides may be focused more on the control of broadleaf species, thus the growth stage or size of the grass species may not always be optimal for herbicide activity. The herbicide labels suggest control of these grass species with mesotrione, topramezone, and tembotrione may be restricted to relatively small grass growth stages (Anonymous 2005; Anonymous 2006). However, there has been very little research conducted that specifically investigates the growth stage limitations of these three herbicides for POST grass control in corn.

The combination of two herbicides for broad spectrum weed control in a single application is a common practice. In some instances, the addition of another herbicide with mesotrione, topramezone, and tembotrione may be justified to improve control of grass species. The ALS-inhibiting herbicides foramsulfuron and nicosulfuron are the most common herbicides used for postemergence control of grass species in non-transgenic corn (USDA 2005) making these herbicides suitable for combining with mesotrione, topramezone, or tembotrione. Tank-mixing ALS-inhibitors with mesotrione may not always result in complementary weed control. Mixing some HPPD-inhibiting herbicides with ALS-inhibiting compounds has resulted in antagonistic herbicide interactions (Kaastra et al. 2008) and can be related to the application rate of the herbicides used in the mixture (Schuster et al. 2004). For example, reducing the rate of mestotrione mixed with foramsulfuron resulted in 27% greater control of green foxtail compared with higher rates of mesotrione (Schuster 2007). In this instance the antagonistic effect was overcome by reducing the amount of mesotrione in the mixture.

Another consideration when applying herbicides for foliar activity is the activator adjuvant used to enhance foliar uptake and overall efficacy of the herbicide (Underwood 2000). Nonionic surfactants (NIS), crop oil concentrates (COC) and methylated seed oils (MSO) are common adjuvants added to spray solutions for foliar applications of herbicides (Young and Hart 1998). All three adjuvant categories will alter the physical properties of the spray solution and improve droplet spread on the target leaf. In addition, moving from NIS to COC to MSO can increase the propensity of the herbicide to penetrate the epicuticular wax of target leaf surface for even greater herbicide activity (Dahl et al. 2005; Young and Hart 1998).

Weed resistance has garnered national news attention in the last few years (Osunsami 2009). University researchers and agricultural professionals have long warned about the effects of overusing one pesticide because of the inevitability of herbicide resistance (Gressel 1978). In Georgia cotton production, for example, overuse of glyphosate has caused weed shifts and decreased the effectiveness of glyphoaste (Webster et al. 2010). For producers, rotating chemicals and tank-mixing herbicides with differing modes of action will delay further selection of herbicide resistant weeds (Boerboom 1999).

Efficient and successful POST weed management in corn relies on having a foundation of knowledge of individual and collective herbicide contributions on target weed species. The POST grass efficacy of the HPPD-inhibiting herbicides may be an important component of weed management strategies and, thus, additional research is necessary to more completely characterize the efficacy of these herbicides. The objectives of this research were to: 1) compare tembotrione with the other HPPD-inhibiting herbicides mesotrione and topramezone for activity on four grass species, 2) compare tembotrione with the ALS-inhibiting herbicides foramsulfuorn and nicosulfuron on four grass species, 3) determine the utility of foramsulfuron and nicosulfuron combinations with tembotrione for activity on grass, and 4) determine the effect of adjuvant and the role of weed size on tembotrione activity.

MATERIALS AND METHODS

Greenhouse studies were conducted to determine the efficacy of tembotrione compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron on large crabgrass, giant foxtail, shattercane, and fall panicum. Seeds of giant foxtail, large crabgrass, shattercane[1] and fall panicum[2] were planted in soil-less potting media[3] in tubes and grown in the greenhouse under supplemental light to provide a 16-h day. The tubes were watered and fertilized[4] as necessary and the seedlings were thinned to one per tube shortly after emergence.

Herbicide treatments included eight rates of each herbicide (0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the typical field use rate) applied in a factorial with NIS[5] (0.25%v/v), COC[6] (1% v/v), and MSO[7] (1% v/v). The registered use rates (1X) for the herbicides were tembotrione at 92 g ai/ha, mesotrione at 104 g ai/ha, topramezone at 18.4 g ai/ha, foramsulfuron at 36.8 g ai/ha, and nicosulfuron at 35 g ai/ha. The commercial

[1]Large crabgrass, giant foxtail, and shattercane seed, Azlin Seed Service, 112 Lilac Dr., Leland, MS 38756.
[2]Fall panicum seed, V & J Seed Farms, PO Box 82, Woodstock, IL 60098.
[3]Conrad Fafard Inc., PO Box 790, 770 Silver St., Agawam, MA 01001.
[4]Scott's fertilizer, 14111 Scottslawn Rd., Marysville, OH 43041.
[5]Activator 90, Loveland Products, 7251 W. 4th St., Greeley, CO 80634.
[6]Prime Oil, Winfield Solutions, PO Box 6421, St. Paul MN, 55164.
[7]Destiny, Winfield Solutions, PO Box 6421, St. Paul MN, 55164.

herbicide products for tembotrione and foramsulfuron were formulated with the safener isoxadifen. The ratio of herbicide and safener is 2:1 for tembotrione:isoxadifen and 1:1 for foramsulfuron:isoxadifen. The herbicide treatments were applied to grass plants that were at the 2- to 3-leaf and 4- to 6-leaf growth stage. Applications were performed with a single nozzle spray booth at 187 L/ha spray volume using an 8002 spray nozzle[8]. Four replications were utilized with pots arranged in a randomized complete block and the experiment was conducted twice.

A second greenhouse study investigated the interaction of tembotrione applied in combination with foramsulfuron and nicosulfuron and adjuvants. The eight rates of foramsulfuron and nicosulfuron applied in the previous experiment were applied with two rates of tembotrione (0.25 and 1X) and the adjuvants COC and MSO. The 1X field rate was used for determining commercial activity and the 0.25X rate was used to allow for sub-lethal activity and greater separation of the treatments. Herbicide treatments were applied to fall panicum at the 2- to 3-leaf and the 4- to 6-leaf growth stage.

Visual estimates of control were taken on a scale of 0 to 100% (0 being no control and 100 being complete control) at 7 and 14 days after treatment (DAT). In addition, grass shoot material was harvested at 14 DAT and placed in an oven at 70 C for 48 h for determination of dry weights.

Dry weight data were then subjected to a four-parameter log-logistic, dose-response regression model using the R software[9] program with the drc package (Ritz and Streibig 2005):

$$y = \mathrm{C} + \frac{\mathrm{D} - \mathrm{C}}{}$$

[8]Even Flat Fan 8002, TeeJet Technologies, 3062 104th St., Urbandale, IA 50322.
[9] R software, Version 2.6.1, The R Foundation for Statistical Computing, Vienna University of Technology, Karlsplatz 13, 1040 Vienna, Austria.

$$1 + \exp[b * \ln(x/ED_{50})]$$

where *y* represents dry weight (as a percentage of the nontreated), C is the lower limit, D is the upper limit, *b* is the slope of the line, ED_{50} is the herbicide dose that gives 50% response, and *x* is herbicide dose. ED_{50} values are represented as a percentage of the recommended rate (1X) for each respective herbicide for ease of making relative comparisons across herbicides. Regression models were reduced, if appropriate, to have common upper and lower limits of activity and slope across each of the herbicide treatments being compared to improve estimations of the ED_{50} values. The ED_{50} values were then compared using an F-test ($\alpha = 0.05$) and the selective index, this produced a ratio of the ED_{50} values. By convention the herbicide with the greater ED_{50} value (lower efficacy) is the numerator and the herbicide with the lower ED_{50} value (greater efficacy) is the denominator. This results in all selective indices being greater than 1 and is representative of the magnitude of difference in the efficacy between the herbicides.

RESULTS AND DISCUSSION

In some instances herbicide activity up to the 2X rate did not achieve 50% growth reduction, and was not sufficient to adequately predict an ED_{50} value using the log-logistic regression analysis. Conversely, the herbicide rate structure was not low enough to properly estimate ED_{50} values on certain weed species in some instances. When regression analysis could not predict the ED_{50} values due to these circumstances the ED_{50} value was estimated as being either greater than the highest rate tested (2X) or less than the lowest rate tested (0.03125X) for the herbicide.

Large Crabgrass

The ED_{50} values for tembotrione on large crabgrass were less than 4% of the 1X rate regardless of weed growth stage or adjuvant (Table 2.1). In comparison, the ED_{50} values for foramsulfuron and nicosulfuron ranged from 11 to 19% and 10 to 82% of the 1X rate on 2- to 3-leaf and 4- to 6-leaf large crabgrass, respectively, when applied with either NIS or COC. The use of MSO with foramsulfuron and nicosulfuron resulted in ED_{50} values of 5% or less of the 1X rate regardless of weed growth stage. Selective indices (ratios of ED_{50} values) demonstrate that tembotrione had greater efficacy than the sulfonylurea herbicides regardless of weed growth stage or adjuvant. The only exception was the ED_{50} values for tembotrione and nicosulfuron when applied with NIS on 4- to 6- leaf large crabgrass. In this instance, tembotrione and nicosulfuron had the same level of activity.

Convergence of the regression curves for tembotrione with mesotrione and topramezone did not allow for an accurate estimation of the ED_{50} values for tembotrione on 2- to 3- leaf large crabgrass due to a high level of growth reduction even at low doses. However, based on the regression analysis used in convergence with foramsulfuron and nicosulfuron the ED_{50} values on 2- to 3-leaf large crabgrass were likely less than 2% of the 1X rate of tembotrione. The ED_{50} values for topramezone and mesotrione on 2- to 3-leaf large crabgrass were also relatively low and ranged from 0.2 to 10% of the 1X rate for each respective herbicide. The efficacy of topramezone was greater than mesotrione on 2- to 3-leaf large crabgrass for all adjuvants with up to 46 times greater efficacy when applied with NIS. Tembotrione had up to 10 times greater efficacy on 4- to 6-leaf large crabgrass than both mesotrione (all adjuvants) and topramezone (NIS and COC). The efficacy of topramezone on 4- to 6-leaf large crabgrass was improved with the use of MSO to the extent that no difference in ED_{50} values were detected with tembotrione.

Previous research has shown that large crabgrass is sensitive to various rates of the ALS-inhibiting herbicides foramsulfuron and nicosulfuron (Baghestani et al. 2007). This supports the results from this test. Also, tembotrione alone may control large crabgrass regardless of adjuvant, but mesotrione proves to have less activity. The option then exists to tank-mix mesotrione with ALS-inhibiting herbicides. In some instances increased activity has been observed on some species when mesotrione has been tank-mixed with foramsulfuron (Bunting et al. 2005).

Fall Panicum

The ED_{50} values for tembotrione on fall panicum were 12 to 20% of the 1X rate when applied with NIS or COC regardless of weed growth stage (Table 2.2). However, the ED_{50} values for tembotrione on fall panicum were 7% or less of the 1X rate when applied with MSO. The ED_{50} values for foramsulfuron and nicosulfuron on fall panicum were less than 7% of the 1X for all parameters. The efficacy of tembotrione and foramsulfuron on fall panicum across both growth stages and all adjuvants were not different based on comparison of the ED_{50} values and selective indices. Conversely, the efficacy of nicosulfuron was 2.7 to 6.7 times greater than tembotrione. The only instance in which the efficacy of tembotrione was not different from nicosulfuron was on 4- to 6-leaf fall panicum applied with MSO. The efficacy of the sulfonylurea herbicides on fall panicum were not different based on a comparison of the ED_{50} values.

The ED_{50} values for HPPD-inhibiting herbicides on fall panicum were relatively greater than for large crabgrass indicating less sensitivity of fall panicum to these herbicides. Tembotrione efficacy on 2- to 3-leaf fall panicum was similar to mesotrione based on the ED_{50} values and selective indices when applied with NIS and COC. Applying tembotrione with MSO resulted in nearly twice the efficacy of mesotrione on 2- to 3-leaf fall panicum. Topramezone had at least twice the efficacy of tembotrione at either growth stage applied with NIS or MSO and was not different from tembotrione when applied with COC. However, topramezone demonstrated greater efficacy on 2- to 3-leaf fall panicum than mesotrione regardless of adjuvant. Minimal efficacy from mesotrione on 4- to 6- leaf fall panicum, regardless of adjuvant, prevented the estimation of accurate ED_{50} values and convergence with the tembotrione and topramezone regression curves (data not presented).

In a study with topramezone it was found that both herbicide and grass species contributed to differences in antagonism in both the field and greenhouse. Topramezone antagonized nicosulfuron activity on large crabgrass and barnyardgrass, but activity on yellow and green foxtail was not influenced. In the same study, topramezone did not antagonize foramsulfuron on any of the species tested (Kaastra et al. 2008).

Many herbicide labels stress proper application timing for control of different weed species. Experiments evaluating herbicide timing have shown significant value in weed control when applied early as opposed to later (Johnson et al. 2002). For fall panicum activity this appears essential when applying HPPD-inhibitors and tank-mixtures.

Giant Foxtail

Tembotrione applied with NIS and COC exhibited 2 to 6 times less efficacy on 2- to 3-leaf giant foxtail compared with foramsulfuron and nicosulfuron (Table 2.3). However, the efficacy of tembotrione was not different from foramsulfuron and nicosulfuron applied to 4- to 6-leaf giant foxtail with COC. Convergence of the regression lines and estimation of the ED_{50} values for tembotrione, foramsulfuron, and nicosulfuron on giant foxtail were not possible for the herbicides applied with NIS (4- to 6-leaf stage) or MSO (both growth stages) due to the high level of efficacy achieved. No difference was observed in the efficacy of foramsulfuron and nicosulfuron on giant foxtail regardless of growth stage or adjuvant.

The efficacy of tembotrione was 1.5 to 4.2 times less on 2- to 3-leaf giant foxtail than topramezone; whereas the efficacy of tembotrione was 2.1 to 5.5 times greater than topramezone on 4- to 6-leaf giant foxtail across all adjuvants. Mesotrione did not provide sufficient efficacy on 2- to 3-leaf giant foxtail which precluded the convergence with the other regression lines and estimates of ED_{50} values. When tembotrione was applied to giant foxtail in the 4- to 6-leaf stage herbicide efficacy was 6 to 8 times greater than with mesotrione. Thus, tembotrione had greater activity on 4- to 6-leaf giant foxtail than either mesotrione or topramezone.

Field studies support this level of giant foxtail control from these HPPD-inhibitors. Both tembotrione and topramezone provide greater control of giant foxtail than mesotrione (Bollman et al. 2008). In addition, greater levels of HPPD-inhibitor activity tended to be observed when applied with MSO as compared to COC or NIS. This supports Young and Hart’s findings from 1998, while examining similar circumstances.

Shattercane

Tembotrione exhibited less efficacy on 2- to 3-leaf shattercane than foramsulfuron (NIS) and nicosulfuron (NIS and COC) (Table 2.4). The ED_{50} values for tembotrione, foramsulfuron, and nicosulfuron applied with MSO on 2- to 3-leaf shattercane were not obtained due to the high level of efficacy achieved within the herbicide dose range. Even though the estimated ED_{50} values for 4- to 6-leaf shattercane varied with up to a 7X difference in the values for tembotrione and nicosulfuron the F-test did not reveal any statistical differences in herbicide efficacy based on the ED_{50} values. The ED_{50} values for nicosulfuron and foramsulfuron were never determined different regardless of shattercane growth stage at application or adjuvant.

Among the HPPD-inhibitors tembotrione always had the lowest ED_{50} value on 2- to 3-leaf shattercane regardless of adjuvant. More specifically, the ED_{50} values for tembotrione were less than 4% of the 1X field use rate which was 6 to 10 times less than mesotrione or topramezone and was not influenced by adjuvant. No differences in the efficacy of the HPPD-inhibiting herbicides were observed on 4- to 6-leaf shattercane regardless of adjuvant.

When looking at shattercane, we again see the effect timing has on shattercane's sensitivity to these herbicides. While the HPPD-inhibitors show varying degrees of activity at the smaller grass stage, there are no differences in activity on 4- to 6- leaf shattercane.

Tank-Mixtures

The sensitivity of fall panicum to foramsulfuron or nicosulfuron was similar for the ALS-inhibiting herbicides alone or in combination with tembotrione (Table 2.5). Thus, the mixture of these herbicides was neither synergistic nor antagonistic, regardless of adjuvant. As was observed in other trials (Bunting et al. 2005) tank-mixing HPPD- and

ALS-inhibiting herbicides is a viable option for foliar applications. There was no decrease in control of fall panicum when tembotrione and the ALS-inhibiting herbicides were tank-mixed. Interestingly, when MSO was applied with either ALS-inhibiting herbicide the ED_{50} was achieved with approximately 1% of the normal herbicide rate. However, the necessary rate of these herbicides to obtain the ED_{50} when applied with COC was at least twice that of MSO. As demonstrated by others, the choice of adjuvant and herbicide timing is essential when optimizing weed control (Dahl et al. 2005; Young and Hart 1998; Johnson et al. 2002).

Dose response experiments can contribute to the basic knowledge of foliar herbicide efficacy and weed species sensitivity (Sikkema et al. 1999). The goals of these experiments were to characterize the foliar grass efficacy of tembotrione compared with other POST herbicides and application parameters. Tembotrione demonstrated greater efficacy on large crabgrass than foramsulfuron, nicosulfuron, mesotrione and topramezone with no influence from weed growth stage or adjuvant. The least sensitive grass species to tembotrione relative to the other herbicides evaluated was fall panicum. If fall panicum is a target weed in field applications our research demonstrated that the combination of foramsulfuron or nicosulfuron with tembotrione may not result in any antagonistic response. The efficacy of tembotrione relative to the other herbicides evaluated was variable on giant foxtail and shattercane with activity dependent on weed growth stage and adjuvant in some instances. The differences in tembotrione efficacy in this research could at least partially explain observations of inconsistent POST grass control under challenging field conditions and application parameters. The use of MSO improved the efficacy of tembotrione with some species such as large crabgrass, however fall panicum showed less selectivity to tembotrione regardless of adjuvant. Therefore, grower practices and industry recommendations should be discouraged from promoting NIS and support the use of a more aggressive adjuvant like MSO.

Table 2.1. Efficacy of tembotrione on large crabgrass at two different growth stages compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron based on plant dry weight reductions at 14 DAT.

	Growth stage					
	2- to 3-Leaf			4- to 6-Leaf		
Herbicides[a]	NIS	COC	MSO	NIS	COC	MSO
Temb vs. ALS Herbs.	--------------- ED_{50} value (% of labeled rate)[b] ---------------					
Temb	1.8	1.3	0.1	3.1	0.5	0.8
Fora	19	12.1	4	29	82	5
Nico	15	11.4	4	9.7	41	2.8
	Selective Index[c]					
Temb:Fora	11*[e]	9.3*	40*	9.3*	164*	6.3*
Temb:Nico	8.1*	8.8*	40*	3.1	82*	3.5*
Fora:Nico	1.3	1.1	1	3	2	1.8
Temb vs. HPPD Herbs.	--------------- ED_{50} value (% of labeled rate) ---------------					
Temb	-[d]	-	-	2.1	1	1.2
Meso	9.2	10	7.1	21	9.5	10
Topr	0.2	4.6	2.4	5.6	5.1	1.7
	Selective Index					
Temb:Meso	-	-	-	9.9*	9.5*	8.4*
Temb:Topr	-	-	-	2.7*	5.1*	1.4
Meso:Topr	46*	2.3*	3*	3.7*	1.9*	5.9*

[a] The rate structure for these herbicides was 0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the registered use rate.

[b] This represents an ED_{50} value as a percentage of the labeled rate for these herbicides.

[c] The selective index is the ratio of ED_{50} values for two herbicides being compared. By convention the herbicide with the greater ED_{50} value (lower efficacy) is the numerator and the herbicide with the lower ED_{50} value (greater efficacy) is the denominator. This results in all selective indices being greater than 1 and is representative of the magnitude of difference in the efficacy between the herbicides. The (*) represents significance and a p-value ≤ 0.05. This significance is valid within adjuvants, not across adjuvants or sizes.

[d] The (-) represents data that is not presented, tembotrione was highly active on 2- to 3- leaf large crabgrass, even at the lowest tested rates.

Table 2.2. Efficacy of tembotrione on fall panicum at two different growth stages compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron based on plant dry weight reductions at 14 DAT.

	Growth stage					
	2- to 3- Leaf			4- to 6- Leaf		
Herbicides[a]	NIS	COC	MSO	NIS	COC	MSO
Temb Vs. ALS Herbs.	--------------------------------% of Labeled rate[b]----------------------					
Temb	20	12	6.1	15	13	7
Fora	4	2.7	1.2	6.9	4.7	1.5
Nico	3.6	2.2	0.9	4.2	4.6	0.8
	Selective Index[c]					
Temb:Fora	4.9	4.5	5.1	2.1	2.7	4.7
Temb:Nico	5.4*	5.5*	6.7*	3.5*	2.7*	8.8
Fora:Nico	1.1	1.2	1.3	1.6	1	1.9
Temb Vs. Other HPPD Herbs.	--------------------------------% of labeled rate------------------------					
Temb	61	14	8.8	23	9.3	6.1
Meso	55	15	16	-[d]	-	-
Topr	17	5.8	1.6	8	9.3	3
	Selective Index					
Temb:Meso	1.1	1.1	1.8*	-	-	-
Temb:Topr	3.5*	2.4	5.5*	2.9*	1	2*
Meso:Topr	3.2*	2.6*	9.8*	-	-	-

[a] The rate structure for these herbicides was 0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the registered use rate.

[b] This represents an ED_{50} value as a percentage of the labeled rate for these herbicides.

[c] The selective index is the ratio of ED_{50} values for two herbicides being compared. By convention the herbicide with the greater ED_{50} value (lower efficacy) is the numerator and the herbicide with the lower ED_{50} value (greater efficacy) is the denominator. This results in all selective indices being greater than 1 and is representative of the magnitude of difference in the efficacy between the herbicides. The (*) represents significance and a p-value ≤ 0.05. This significance is valid within adjuvants, not across adjuvants or sizes.

[d] The (-) represents data that is not presented, minimal efficacy from mesotrione resulted in lack of convergence for 4- to 6- leaf fall panicum.

Table 2.3. Efficacy of tembotrione on giant foxtail at two different growth stages compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron based on plant dry weight reductions at 14 DAT.

	Growth stage					
	2- to 3- Leaf			4- to 6- Leaf		
Herbicides[a]	NIS	COC	MSO	NIS	COC	MSO
Temb Vs. ALS Herbs.	---------------------------------% of labeled rate[b]-----------------------					
Temb	21	12	-[d]	-	9.2	-
Fora	5	4.8	-	-	5.1	-
Nico	3.2	5	-	-	2.1	-
	Selective Index[c]					
Temb:Fora	4.2*	2.6*	-	-	1.8	-
Temb:Nico	6.5*	2.5*	-	-	4.4	-
Fora:Nico	1.6	1	-	-	2.4	-
Temb Vs. Other HPPD Herbs.	---------------------------------% of labeled rate-------------------------					
Temb	23	12	11	13	8.8	3.6
Meso	-	-	-	76	66	29
Topr	6.3	7.5	2.7	26	49	14
	Selective Index					
Meso:Temb	-	-	-	6.1*	7.5*	8*
Temb:Topr	3.7*	1.5*	4.2*	2.1*	5.5*	3.9*
Meso:Topr	-	-	-	2.9	1.4	2.1

[a] The rate structure for these herbicides was 0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the registered use rate.

[b] This represents an ED_{50} value as a percentage of the labeled rate for these herbicides.

[c] The selective index is the ratio of ED_{50} values for two herbicides being compared. By convention the herbicide with the greater ED_{50} value (lower efficacy) is the numerator and the herbicide with the lower ED_{50} value (greater efficacy) is the denominator. This results in all selective indices being greater than 1 and is representative of the magnitude of difference in the efficacy between the herbicides. The (*) represents significance and a p-value $\leq$ 0.05. This significance is valid within adjuvants, not across adjuvants or sizes.

[d] The (-) represents data that is not presented, high levels of activity were observed with tembotrione, foramsulfuron, and nicosulfuron with MSO on both size grass. High levels of activity were also observed with NIS on 4- to 6- leaf giant foxtail. Alternatively, low efficacy was observed with mesotrione across all adjuvants on 2- to 3- leaf giant foxtail.

Table 2.4. Efficacy of tembotrione on shattercane at two different growth stages compared with mesotrione, topramezone, foramsulfuron, and nicosulfuron based on plant dry weight reductions at 14 DAT.

	Growth stage					
	2- to 3- Leaf			4- to 6- Leaf		
Herbicides[a]	NIS	COC	MSO	NIS	COC	MSO
Temb Vs. ALS Herbs.	--------------------------------%of labeled rate [b]----------------------					
Temb	4.3	3.2	- [d]	7.4	10	13
Fora	2.1	2.4	-	7.4	4.8	15
Nico	1.7	1.9	-	7.4	3.9	1.8
	Selective Index[c]					
Temb:Fora	2*	1.3	-	1	2.1	1.1
Temb:Nico	2.5*	1.7*	-	1	2.6	7.3
Fora:Nico	1.7	1.3	-	1	1.2	8.1
Temb Vs. Other HPPD Herbs.	---------------------------------% of labeled rate------------------------					
Temb	3.7	2.8	2	24	20	11
Meso	39	25	18	30	16	13
Topr	24	27	14	9.6	11	6.4
	Selective Index					
Temb:Meso	11*	8.9*	9.1*	1.3	1.2	1.2
Temb:Topr	6.4*	9.6*	6.9*	2.5	1.9	1.7
Meso:Topr	1.7*	1.1	1.3	3.1	1.5	2

[a] The rate structure for these herbicides was 0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the registered use rate.

[b] This represents an ED_{50} value as a percentage of the labeled rate for these herbicides.

[c] The selective index is the ratio of ED_{50} values for two herbicides being compared. By convention the herbicide with the greater ED_{50} value (lower efficacy) is the numerator and the herbicide with the lower ED_{50} value (greater efficacy) is the denominator. This results in all selective indices being greater than 1 and is representative of the magnitude of difference in the efficacy between the herbicides. The (*) represents significance and a p-value ≤ 0.05. This significance is valid within adjuvants, not across adjuvants or sizes.

[d] The (-) represents data that is not presented, high levels of activity were observed with tembotrione, foramsulfuron, and nicosulfuron on 2- of 3- leaf shattercane when used with MSO.

Table 2.5. Sensitivity of fall panicum to foramsulfuron and nicosulfuron applied individually and in mixture with tembotrione, at two rates, and the adjuvants coc and mso. [a]

Tank-mix herbicide[b]	Tembotrione rate (g/ha)	COC	MSO
		------------------% of labeled rate------------[c]	
Fora	0	4.3	1
Fora	23	4.3	1
Fora	92	4.3	1
		Selective index[d]	
Fora:Fora+Temb(23g)		1	1
Fora:Fora+Temb(92g)		1	1
Fora+Temb(23g):Fora+Temb(92g)		1	1
		------------------% of labeled rate------------	
Nico	0	2.6	1.1
Nico	23	2.6	1.1
Nico	92	2.6	1.1
		Selective Index	
Nico:Nico+Temb(23g)		1	1
Nico:Nico+Temb(92g)		1	1
Nico+Temb(23g):Nico+Temb(92g)		1	1

[a] This data originates from dry weights taken 14 days after treatment

[b] The rate structure for these herbicides was 0, 0.03125, 0.0625, 0.125, 0.25, 0.5, 1, and 2 times the registered use rate.

[c] This represents an ED_{50} value as a percentage of the labeled rate for these herbicides

[d] The selective index is a ratio between each ED_{50} value representing how much of one herbicide it takes to equal the activity of the other.

CHAPTER 3

INFLUENCE OF HERBICIDES AND ADJUVANTS WITH TEMBOTRIONE FOR FALL PANICUM CONTROL

Abstract. Field studies were conducted in 2006 and 2007 at Carbondale and Belleville Illinois to examine the effect of postemergence applications of tembotrione alone and in combination with foramsulfuron, nicosulfuron, and atrazine on fall panicum when applied with either crop oil concentrate (COC) or methylated seed oil (MSO). To examine the influence of atrazine with tembotrione, tembotrione was utilized at two different rates with either atrazine or nicosulfuron and atrazine. It was found that tembotrione alone does not control fall panicum. Control was observed over 90% when utilized with a sulfonylurea herbicide. Tank-mixtures of tembotrione with a full rate of nicosulfuron provided 91% control while tank-mixtures with a full rate of foramsulfuron provided 86% control. When examining adjuvant use in these tank-mixtures, combinations with MSO provided greater control than combinations with COC. Visual control differences of up to 30% were observed when MSO was used rather than COC. Rate of the sulfonylurea herbicide also influenced fall panicum control. When combined with tembotrione, as sulfonylurea herbicide rate increased, fall panicum control also increased. It was also observed that the addition of atrazine to a tembotrione and nicosulfuron combination did not negatively influence control of fall panicum, 85% control was observed both with and without atrazine.

Nomenclature: Atrazine, foramsulfuron, mesotrione, tembotrione, fall panicum, *Panicum dichotomiflorum* #[10] PANDI; corn, *zea mays*.

Additional index words: Antagonsim, crop oil concentrate, herbicide interactions, methylated seed oil, *p*-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors, synergy, tank-mixtures.

INTRODUCTION

Tembotrione is an HPPD-inhibiting herbicide for selective control of grass and broadleaf weed species in postemergence applications in field corn (Schulte and Kocher 2009). A commercial formulated product contains tembotrione as the sole herbicide active ingredient with a common use rate of 92 g ai/ha (Hinz et al. 2005). This product is also formulated with the crop safener isoxadifen in a 2:1 ratio of tembotrione:isoxadifen. Thus, when tembotrione is applied at 92 g ai/ha the rate of isoxadifen is 46 g ai/ha (Bollman et al. 2008). Mesotrione is also an HPPD-inhibitor and is active on a variety of broadleaf weeds, but only some grass species (Mitchell et al. 2001). Many producers mix herbicides for application at one time, also known as tank-mixing. Often mesotrione has been tank-mixed with herbicides known to control grasses to improve the control of grass species (Armel et al. 2003a).

Nicosulfuron and foramsulfuron are two sulfonylurea herbicides that have shown excellent grass control and may prove beneficial in tank-mixtures with new HPPD-inhibiting herbicides such as tembotrione and mesotrione. Mesotrione does not control giant foxtail or fall panicum (Armel et al. 2003), however, foramsulfuron has acceptable

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[10] Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence KS 66044-8897.

control of both of these species (Bunting et al. 2005). Foramsulfuron in combination with mesotrione have shown little differences in giant foxtail and fall panicum control, and increased broadleaf control compared to foramsulfuron alone (Bunting et al. 2005). Antagonistic herbicide interactions describe when a decrease in biological activity occurs for the combined herbicide mixture compared to the each herbicide applied alone. This antagonism has been observed when adding mesotrione to foramsulfuron or nicosulfuron on some grass species, compared to applications of foramsulfuron or nicosulfuron alone (Schuster et al. 2004). Reducing the rate of mestotrione mixed with foramsulfuron resulted in 27% greater control of green foxtail (Schuster 2007).

Atrazine is another widely used corn herbicide for control of many weeds and may be useful to producers in tank-mix combinations (USDA 2005). Interestingly, synergism has been observed when atrazine is combined with HPPD-inhibitors (Abendroth et al. 2006). Atrazine is a photosystem II inhibitor, and acts by binding to the D1, quinone-binding protein blocking electron transport in the electron transport chain of photosynthesis (Duke 1990). Atrazine is suggested in tank-mixtures with other HPPD-inhibitors such as mesotrione. Mesotrione applied postemergence has been shown to have little effect on green foxtail, but when applied with atrazine plant death occurs. This suggests that mesotrione and atrazine are working together attacking the plants carotenoid biosynthesis and photosystem II pathways (Creech et al. 2004). However, atrazine may antagonize some chemistries. Significant reductions in giant foxtail control have been observed when atrazine was added to nicosulfuron, (Dobbels and Kapusta 1993) and reductions in control of giant foxtail and fall panicum were also observed when atrazine was added to foramsulfuron, depending on adjuvant selection (Bunting et al. 2005).

Research has been conducted with postemergence HPPD- inhibiting herbicides and the effects of tank-mixing an HPPD-inhibitor with a photosystem II inhibitor and a sulfonylurea herbicide. Antagonism has been observed with the combination of mesotrione, atrazine, and the sulfonylurea herbicides, foramsulfuron or nicosulfuron. Some grass species were insufficiently controlled with this combination of herbicides (Schuster et al. 2004). This is discouraging while trying to incorporate new chemicals into weed management systems, while still maintaining needed control of trouble weed species.

Weed resistance has garnered national news attention in the last few years (Osunsami 2009). University researchers and agricultural professionals have long warned about the effects of overusing one pesticide because of the inevitability of herbicide resistance (Gressel 1978). In Georgia cotton production, for example, overuse of glyphosate has caused weed shifts and decreased the effectiveness of glyphoaste (Webster et al. 2010). For producers, rotating chemicals and tank-mixing herbicides with differing modes of action will delay further selection of herbicide resistant weeds (Boerboom 1999).

In addition to tank-mixing, choosing proper adjuvants will aid in herbicide efficacy. The correct adjuvant used in conjunction with certain herbicides can have great benefits for weed control (Underwood 2000). In foliar applications of isoxaflutole, combinations utilizing methylated seed oil (MSO) had greater efficacy than combinations with crop oil concentrate (COC) (Young and Hart 1998). Penetrating agents are commonly used with herbicides to help herbicide efficiency. These penetrating agents describe adjuvants used to assist the movement of the herbicide for the leaf surface of a weed through natural barriers into the plant. Crop oil concentrate is derived from paraffin crude oil, or petroleum, and contains 20% or less surfactant and a minimum of 80% phytobland oil (Hazen 2000). Another option commonly used in place of crop oil concentrate is methylated seed oil. Methylated seed oil is a type of oil that has been extracted from crops and further methylated (Hazen 2000). Research conducted with isoxaflutole and the grass giant foxtail has shown vast improvements in efficacy when an adjuvant is applied in combination with isoxaflutole (Young and Hart 1998). More specifically, some herbicide manufacturers discourage the use of MSO because it may enhance foliar efficacy to the point where crop injury may occur from the herbicide. However, for herbicide efficacy on weed species research suggests that herbicides applied with MSO have performed as well as or better than the same herbicide applied with COC (Dahl et al. 2005).

The objectives of this research were to evaluate control of fall panicum with POST tembotrione applications through: 1) the combination of different rates of nicosulfuron and foramsulfuron with tembotrione, 2) the addition of atrazine to tembotrione applied with and without nicosulfuron, 3) the role of tembotrione dose in atrazine tank mixtures, and 4) the utility of different activator adjuvants with all the herbicide combinations.

MATERIALS AND METHODS

Two field experiments were conducted in 2006 and 2007 at the Agricultural Research Center in Carbondale and the Belleville Research Center in Belleville, Illinois. The first experiment was designed to determine the effect of tank-mixing nicosulfuron and foramsulfuron at different application rates and adjuvant systems with tembotrione. Since the efficacy of tembotrione applied alone was minimal, a second experiment was designed to determine if the addition of atrazine in mixtures with tembotrione and tembotrione plus nicosulfuron or foramsulfuron could improve herbicide efficacy on fall panicum. The soil type at both locations was a Weir silt loam with 1.5% organic matter content and 6.7 pH at Carbondale and a 2.2% organic matter content and 6.2 pH at Belleville. Each plot consisted of four rows in 76-cm row spacing for a dimension of 3m wide by 7.6 to 8.5m long. Hybrid seed corn[11] was planted approximately 3cm deep at 61,690 seeds/ha.

In the first experiment a total of 18 herbicide treatments were evaluated and included tembotrione (92 g ai/ha) applied alone, tembotrione applied with four rates each of foramsulfuron (9.3, 18.5, 27.8, and 37 g ai/ha) and nicosulfuron (6.5, 13,19.5, and 26 g ai/ha) which correspond to 0.25, 0.5, 0.75, and 1X the normal use rate, and all herbicides combinations applied with the two activator adjuvants crop oil concentrate (COC) and methylated seed oil (MSO) at 1% v/v. The second experiment contained 16 herbicide treatments and was a factorial of tembotrione rate (61 and 92 g ai/ha), tank-mixture with tembotrione (none, nicosulfuron (13 g ai/ha), and nicosulfuron plus atrazine (560 g

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[11] Pioneer 33K44 and Pioneer 31G96 hybrid corn seed was planted in Belleville and Carbondale, respectively. Pioneer Hi-Bred, P.O. Box 1000, Johnston, IA 50131.

ai/ha)), and activator adjuvant (COC and MSO at 1% v/v). All herbicides treatments in both experiments included 28% urea ammonium nitrate (UAN) at 2.5% v/v. Herbicides were applied when fall panicum was 5.5 to 10cm in height using a compressed CO_2 backpack sprayer using a 2.3m hand-held boom. The boom was equipped with Turbo Teejet 8002 flat fan nozzles[12] calibrated to deliver 187 L/ha at 276 kPa.

Visual estimates of corn injury and weed control were taken at 14 and 28 days after treatment (DAT). All data were analyzed in PROC GLM procedure from [SAS/STAT] software. The data were subjected to analysis of variance and means were separated using Fisher's protected LSD test ($\alpha = 0.05$). The data from the studies with foramsulfuron and nicosulfuron tank-mixed with tembotrione were transformed using arcsine transformation. The transformed means were analyzed, but the original means are presented since the values have relative importance pertaining to the level of field control of the species.

RESULTS AND DISCUSSION

Tembotrione Tank-Mixtures with Foramsulfuron and Nicosulfuron

Corn injury data was taken at 14 days after treatment (DAT). However no crop injury was observed from tembotrione applications at any point during the experiment. Additionally, no crop injury was observed in tank-mix combinations with tembotrione and other herbicides or adjuvants. Therefore, crop injury data is not presented. Additionally, corn injury should not be used to decide feasibility of tank-mixtures. Tank-mix decisions should be made based on herbicide efficacy.

[12] Turbo TeeJet nozzle by TeeJet Technologies, 3062 104th St., Urbandale, IA 50322.

The interaction of tembotrione with tank-mix partner, and tank-mix partner rate, and adjuvant was significant for control of fall panicum at 14 days after application (Table 3.1). Control of fall panicum with tembotrione alone was 4% or less at 14 DAT with either adjuvant. The addition of both foramsulfuron and nicosulfuron increased control of fall panicum with incremental improvements in control as the rate of the tank-mix partner was increased. This supports previous experiments examining HPPD-inhibiting herbicides being tank-mixed to help control species with marginal sensitivity (Armel et al. 2003a). Control of fall panicum with combinations of tembotrione, foramsulfuron, and COC plateaued at 79% with the 0.75X rate of foramsulfuron. The same herbicide combination applied with MSO plateaued at 82% with the lower foramsulfuron rate of 0.5X. Previous work has shown similar results where weed control in herbicide combinations with MSO exceeded combinations with COC (Dahl et al. 2005, Young and Hart 1998). Combinations of tembotrione with nicosulfuron improved control of fall panicum to a relatively greater extent with MSO than COC. More specifically, the 1X rate of nicosulfuron with tembotrione and COC was necessary to obtain the same level of fall panicum control as with the 0.5X rate of nicosulfuron and MSO. This research demonstrates that the use of MSO can benefit tank-mixtures of foramsulfuron and nicosulfuron to achieve greater control of fall panicum with lower tank-mix partner rates. If COC is being used, higher rates of foramsulfuron or nicosulfuron are suggested

Tembotrione Tank-Mix Study with Atrazine and/or Nicosulfuron

Control of fall panicum at 14 DAT was not influenced by either the rate of tembotrione (61 or 92 g/ha) or adjuvant (COC or MSO). Thus, data for fall panicum control at 14 DAT are presented by the only significant main effect of tank-mix partner with tembotrione (Table 3.2). The application of tembotrione alone resulted in only 3% control of fall panicum. The addition of nicosulfuron to tembotrione improved control of fall panicum to 80%. The addition of atrazine provided no increase in control of fall panicum when combined with tembotrione or tembotrione plus nicosulfuron. Even though atrazine did not enhance control of fall panicum the absence of grass antagonism for this weed species may allow for combinations of atrazine with tembotrione for more effective broadleaf weed control without compromising grass efficacy on fall panicum.

Through both of these studies it is evident the use of a tank-mix partner is necessary for fall panicum control in tembotrione applications. Growers will enhance the control of certain grasses with combinations of tembotrione and a sulfonylurea herbicide. Usually methylated seed oil in combination with tembotrione and nicosulfuron provided greater activity than other options. This will allow growers more consistent control in their herbicide applications. The second field study showed the ability of tembotrione to be tank-mixed with atrazine and nicosulfuron without compromising the fall panicum control. The use of tank-mixed herbicides is common practice. Rate variations and choice of partners are often experimented with. This study shows that varying tembotrione rate does not influence control of fall panicum when mixed with atrazine and nicosulfuron.

Table 3.1 Control of fall panicum at 14 days after postemergence treatment as influenced by tembotrione, tank-mix partner, tank-mix partner rate, and adjuvant from field experiments conducted at Carbondale and Belleville, IL in 2006 and 2007.

		Adjuvant			
Herbicide	Herbicide rate[a]	COC		MSO	
	g/ha	------------- %[b] -------------			
Tembotrione	92	4	i	2	i
Tembotrione + foramsulfuron	92 + 9.3	40	h	77	cde
Tembotrione + foramsulfuron	92 + 18.5	65	g	82	a-d
Tembotrione + foramsulfuron	92 + 27.8	79	b-e	85	ab
Tembotrione + foramsulfuron	92 + 37	79	b-e	85	ab
Tembotrione + nicosulfuron	92 + 6.5	66	fg	77	cde
Tembotrione + nicosulfuron	92 + 13	73	ef	81	a-d
Tembotrione + nicosulfuron	92 + 19.5	75	de	85	ab
Tembotrione + nicosulfuron	92 + 26	82	abc	86	a

[a] Tank-mix partner rate is represented by the percent of the labeled rate.

[b] Percent visual control based on a 0 to 100 scale, where 100 = complete death. Values preceding the same letter are not significantly different.

Table 3.2 Field Studies Conducted at Carbondale and Belleville in 2006 and 2007 Examining the Influence of Nicosulfuron and/or Atrazine with Tembotrione on the Visual Control of Fall Panicum 14 Days After Application.

<table>
<tr><th></th><th colspan="2">Tembotrione Rate (g/ha)</th></tr>
<tr><th>Tank-Mix Herbicide</th><th>61</th><th>92</th></tr>
<tr><td></td><td colspan="2">% Control [a]</td></tr>
<tr><td>None</td><td colspan="2">3 b</td></tr>
<tr><td>Atrazine</td><td colspan="2">2 b</td></tr>
<tr><td>Nicosulfuron</td><td colspan="2">80 a</td></tr>
<tr><td>Atrazine + nicosulfuron</td><td colspan="2">79 a</td></tr>
</table>

[a] Percent visual control based on a 0 to 100 scale, where 100 = complete death. Values preceding the same letter are not significantly different.

CHAPTER 4

CONCLUSIONS

The ED_{50} values obtained through greenhouse studies revealed different levels of activity for each of three HPPD-inhibiting herbicides. Field rate titrations may be necessary to understand commercial levels of control and activity. However, it appears tembotrione has very high levels of activity of large crabgrass and shattercane, while topramezone has high levels of activity of giant foxtail. While tembotrione was not the most effective HPPD-inhibitor on giant foxtail, the level of control should be commercially acceptable in the field. Additional greenhouse work could be conducted with topramezone in combination with foramsulfuron or nicosulfuron on these species to discover any effects on control. As for tank-mixtures with tembotrione and foramsulfuron or nicosulfuron, it appears that no antagonism on fall panicum is observed when compared to nicosulfuron or foramsulfuron applied alone. Seeing as tembotrione has very low levels of activity on fall panicum, a tank-mixture with either nicosulfuron or foramsulfuron would be the solution for gaining control. Also, mesotrione appears to be the least effective HPPD-inhibitor on grasses. Research on tank-mixtures with mesotrione would help in understanding any effects on grass control. As for activity in a three-way mixture, sufficient work needs to be conducted on all of these grass species with the HPPD-inhibitors plus an ALS-inhibitor and atrazine. This research also supports the fact that MSO is generally a more aggressive adjuvant than COC or NIS. MSO should be used for maximum herbicide activity, however, crop safety should be considered. MSO is a more aggressive adjuvant, therefore unacceptable injury may occur. From the field experiments, it appears tembotrione is safe to be used with MSO. The field experiments confirm tembotrione has very low levels of activity on fall panicum. However adding foramsulfuron or nicosulfuron to tembotrione, commercially acceptable levels of control can be obtained. Additionally the three-way mixture of tembotrione, nicosulfuron, and atrazine appears to be safe and effective for fall panicum control in the field. Work needs to be conducted with tembotrione alone and in these tank-mixtures on additional grasses to determine the spectrum of activity. Field work could also be conducted with topramezone and mesotrione to discover if two- or three-way tank mixtures effect grass control.

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APPENDICES

Appendix A

Table A.1

2- to 3- LEAF LARGE CRABGRASS

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.16228	0.11635	0.032507
Nicosulfuron	0.16228	0.11635	0.032507

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1	1

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Mesotrione	0.092305	0.103561	0.07113
Topramezone	0.002643	0.046036	0.024704

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Mesotrione : Topramezone	34.9277 (<0.00)	2.24955 (<0.00)	2.87924 (<0.00)

Appendix A

Table A.2

4- to 6- LEAF LARGE CRABGRASS

Sulfonylurea Herbicides

HERBICIDE	ED50 with COC	ED50 with MSO
Foramsulfuron	0.19315	0.052037
Nicosulfuron	0.19315	0.052037

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.02063	0.010428	0.011885
Mesotrione	0.206521	0.094851	0.101248
Topramezone	0.056212	0.051485	0.016959

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Mesotrione	0.099892 (<0.00)	0.109942 (<0.00)	0.11738 (<0.00)
Tembotrione : Topramezone	0.366999 (<0.00)	0.202546 (<0.00)	0.700779 (0.0593)
Mesotrione : Topramezone	3.673966 (<0.00)	1.84229 (<0.00)	2.87924 (<0.00)

Appendix A

Table A.3

2- TO 3- LEAF FALL PANICUM

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.039246	0.026021	0.013873
Nicosulfuron	0.039246	0.026021	0.037315

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1	0.37179 (0.9024)

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.60636	0.137528	0.087931
Mesotrione	0.54658	0.152516	0.157047
Topramezone	0.17187	0.057752	0.015732

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Mesotrione	1.10936 (0.7293)	0.137528 (0.7593)	0.087931 (0.0014)
Tembotrione : Topramezone	3.52791 (0.0104)	0.152516 (0.0967)	0.157047 (0.0031)
Mesotrione : Topramezone	3.18012 (0.0137)	0.057752 (0.0475)	0.015732 (0.0011)

Appendix A

Table A.4

4- to 6- LEAF FALL PANICUM

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.055332	0.047164	0.00526
Nicosulfuron	0.055332	0.047164	0.00526

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1	1

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.233071	0.093408	0.060826
Topramezone	0.079072	0.093408	0.02976

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Topramezone	2.94757 (<0.00)	1	2.04389 (0.0049)

Appendix A

Table A.5

2- to 3- LEAF GIANT FOXTAIL

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.046942	0.050127	0.22273
Nicosulfuron	0.031692	0.050127	0.050127

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1.4812 (0.0043)	1	1.3137 (0.7127)

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.230589	0.116293	0.113846
Topramezone	0.063216	0.074973	0.026809

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Topramezone	3.64764 (<0.00)	1.55113 (0.0025)	4.24647 (<0.00)

Appendix A

Table A.6

4- TO 6- LEAF GIANT FOXTAIL

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.92478	0.061252	0.032374
Nicosulfuron	0.92478	0.061252	0.003762

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1	8.60475 (0.8424)

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.12456	0.087562	0.036174
Mesotrione	0.75907	0.663835	0.287907
Topramezone	0.26436	0.485512	0.139157

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Mesotrione	0.1641 (<0.00)	0.131903 (<0.00)	0.125646 (<0.00)
Tembotrione : Topramezone	0.471181 (<0.00)	0.180349 (<0.00)	0.259954 (<0.00)
Mesotrione : Topramezone	2.871314 (0.1451)	1.367289 (0.4266)	2.068939 (0.0533)

Appendix A

Table A.7

2- TO 3- LEAF SHATTERCANE

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC
Foramsulfuron	0.050127	0.028336
Nicosulfuron	0.050127	0.022005

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1,28766 (0.0214)

HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.036835	0.028332	0.020095
Mesotrione	0.393514	0.247926	0.18061
Topramezone	0.238211	0.269107	0.136707

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Mesotrione	0.093604 (<0.00)	0.114275 (<0.00)	0.111261 (<0.00)
Tembotrione : Topramezone	0.15463 (<0.00)	0.105281 (<0.00)	0.146992 (<0.00)
Mesotrione : Topramezone	1.651953 (0.0356)	0.92129 (0.6335)	1.321147 (0.1404)

Appendix A

Table A.8

4- TO 6- LEAF SHATTERCANE

Sulfonylurea Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Foramsulfuron	0.059193	0.044556	0.543118
Nicosulfuron	0.059193	0.044556	0.048583

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Foramsulfuron : Nicosulfuron	1	1	11.17914 (0.9762)

\ HPPD-Inhibiting Herbicides

HERBICIDE	ED50 with NIS	ED50 with COC	ED50 with MSO
Tembotrione	0.238182	0.1947	0.106304
Mesotrione	0.301356	0.16233	0.125287
Topramezone	0.096297	0.10547	0.064453

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Tembotrione : Mesotrione	0.79037 (0.6633)	1.19934 (0.7755)	0.84849 (0.7661)
Tembotrione : Topramezone	2.4734 (0.1936)	1.84605 (0.411)	1.64933 (0.4798)
Mesotrione : Topramezone	3.12943 (0.2676)	1.53922 (0.471)	1.94384 (0.3295)

Table A.9
Foramsulfuron alone and in tank-mixtures with tembotrione

TREATMENT	ED50 with COC	ED50 with MSO
Foramsulfuron	0.04273	0.010138
Foramsulfuron + Tembotrione[13]	0.04273	0.010138
Foramsulfuron + Tembotrione[14]	0.04273	0.010138
COMPARISON	**SELECTIVE INDEX (p-value)**	**SELECTIVE INDEX (p-value)**
Foramsulfuron : Foramsulfuron + Tembotrione[2]	1	1
Foramsulfuron : Foramsulfuron + Tembotrione[3]	1	1
Foramsulfuron + Tembotrione[2] : Foramsulfuron + Tembotrione[3]	1	1

[13] Tembotrione at 23 g ai/ha
[14] Tembotrione at 92 g ai/ha

Appendix A

Table A.10

2- to 3- LEAF FALL PANICUM

Nicosulfuron alone and in tank-mixtures with tembotrione

TREATMENT	ED50 with COC	ED50 with MSO
Nicosulfuron	0.025639	0.010995
Nicosulfuron + Tembotrione[15]	0.025639	0.010995
Nicosulfuron + Tembotrione[16]	0.025639	0.010995

COMPARISON	SELECTIVE INDEX (p-value)	SELECTIVE INDEX (p-value)
Nicosulfuron : Nicosulfuron + Tembotrione[4]	1	1
Nicosulfuron : Nicosulfuron + Tembotrione[5]	1	1
Nicosulfuron + Tembotrione[4] : Nicosulfuron + Tembotrione[5]	1	1

[15] Tembotrione at 23 g ai/ha
[16] Tembotrione at 92 g ai/ha

Appendix B

Table B.1
Tembotrione Tank-Mixed with Atrazine or Nicosulfuron and Atrazine

TREATMENT	Rates
Nontreated	
Tembotrione	92 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Atrazine	560 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Atrazine	560 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Atrazine	560 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Atrazine	560 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Atrazine	560 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Nicosulfuron	13 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Nicosulfuron	13 g ai/ha
Atrazine	560 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Atrazine	560 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Nicosulfuron	13 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	61 g ai/ha
Nicosulfuron	13 g ai/ha
Atrazine	560 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v

Appendix B

Table B.2
Tembotrione Tank-Mixed with Sulfonylurea Herbicides

TREATMENT	Rates
Nontreated	
Tembotrione	92 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	6.5 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	19.5 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	26 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	9.3 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	18.5 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	27.8 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5 % v/v
Tembotrione	92 g ai/ha
Foramsulfuron	37 g ai/ha
Crop Oil Concentrate	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	6.5 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	13 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	19.5 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Nicosulfuron	26 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	9.3 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	18.5 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v
Tembotrione	92 g ai/ha
Foramsulfuron	27.8 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5 % v/v
Tembotrione	92 g ai/ha
Foramsulfuron	37 g ai/ha
Methylated Seed Oil	1% v/v
28% UAN	2.5% v/v

Appendix B

Table B.3
Fall Panicum Control 14 Days After Application Examining Adjuvant, Tank-Mix Partner, and Tank-Mix Partner Rate with Tembotrione

Adjuvant	Tank-Mix Partner	Tank-Mix Partner Rate	Mean[a] (%)	Significance level[b]
MSO	Nicosulfuron	1X	86	a
MSO	Foramsulfuron	0.75X	85	ab
MSO	Nicosulfuron	0.75X	85	ab
MSO	Foramsulfuron	1X	85	ab
COC	Nicosulfuron	1X	82	abc
MSO	Foramsulfuron	0.5X	82	abcd
MSO	Nicosulfuron	0.5X	81	abcd
COC	Foramsulfuron	0.75X	79	bcde
COC	Foramsulfuron	1X	79	bcde
MSO	Foramsulfuron	0.25X	77	dce
MSO	Nicosulfuron	0.25X	77	dce
COC	Nicosulfuron	0.75X	75	de
COC	Nicosulfuron	0.5X	73	ef
COC	Nicosulfuron	0.25X	66	fg
COC	Foramsulfuron	0.5X	65	g
COC	Foramsulfuron	0.25X	40	h
COC	None	N/A	4	i
MSO	None	N/A	2	i

[a] Fall Panicum was visually rated for overall injury on a scale of 0 to 100, with 0 being no control and 100 being complete death.

[b] Means within a column followed by the same letter do not differ significantly according to Fisher’s protected LSD, $p \leq 0.05$.

Appendix B

Table B.4

Fall Panicum Control 14 Days After Treatment Examining the Influence of Nicosulfuron and/or Atrazine with Tembotrione

Tank-Mix Partner	Mean[a] (%)	Significance level[b]
Nicosulfuron	80	A
Nicosulfuron & Atrazine	79	A
Tembotrione Alone	3	B
Atrazine	2	B

[a] Fall Panicum was visually rated for overall injury on a scale of 0 to 100, with 0 being no control and 100 being complete death.

[b] Means within a column followed by the same letter do not differ significantly according to Fisher's protected LSD, $p \leq 0.05$.

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