AGRONOMIC AND PEST INTERACTIONS IN NO-TILL CORN AND SOYBEAN WITH FALL VERSUS SPRING HERBICIDE APPLICATIONS

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To my uncle, Robert Reich

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AGRONOMIC AND PEST INTERACTIONS IN NO-TILL CORN AND SOYBEAN WITH FALL VERSUS SPRING HERBICIDE APPLICATIONS

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ABSTRACT

Recent increases in the utilization of no-till production systems and glyphosate-resistant crops have provided environments conducive to winter annual weed establishment. This coupled with the ability to better distribute spring workloads has sparked interest in fall herbicide applications. However, little is known of how fall herbicide applications impact soil conditions, insect populations, and winter and summer annual weed populations. Similarly, few studies have directly compared fall herbicide applications to early spring applications. Therefore, the objectives of these experiments were to 1) evaluate the efficacy of fall versus spring herbicide applications on winter annual weed populations and the emergence of summer annual weed seedlings, 2) determine the impact of fall and early spring herbicide applications on soil temperature, soil moisture, and insect populations, and 3) evaluate differences in weed control obtained with residual and non-residual herbicide applications. Studies were conducted in both no-till corn and soybean fields from 2004 through 2006 in central, northwest, and northeast Missouri. Soybean experiments received applications of chlorimuron plus sulfentrazone plus 2,4-D, chlorimuron plus tribenuron plus 2,4-D, and glyphosate plus 2,4-D in the fall, 60 days prior to planting, 30 days prior to planting, and seven days prior to planting. Applications of simazine plus 2,4-D, rimsulfuron plus thifensulfuron plus 2,4-D, and glyphosate plus 2,4-D were made to corn experiments in the fall, 45 days prior to planting, 30 days prior

to planting, and seven days prior to planting. Measurements of soil moisture and insect populations revealed no significant impact of application timing. However, removal of winter annual weeds with any of the herbicide treatments led to an increase in soil moisture just after planting and a decrease in insect populations and feeding up to seven weeks after planting. Measurements of soil temperature indicated that removing winter annual weeds could increase temperatures in the spring, however, this result was only consistently obtained when soil temperatures were above 20°C. Evaluations of weed control exposed significant differences in treatments and application timings. Fall residual herbicide treatments provided the highest level of winter annual weed control. However, these treatments provided poor control of summer annual weed species after planting. Residual herbicide applications made at the last spring timing provided the highest level of summer annual weed control, but poor winter annual weed control. Residual herbicide applications made 60 or 45 days prior to planting offered the best balance between winter and summer annual weed control. Based on the results of these experiments, no-till producers can obtain maximum weed control and planting conditions by applying chlorimuron plus sulfentrazone plus 2,4-D 60 days prior to planting in soybean, and simazine plus 2,4-D 45 days prior to planting in corn.

CHAPTER I

Literature Review

Research Justification. Fall-applied herbicide usage is currently increasing in no-till corn and soybean fields throughout the Midwest. One of the reasons for this is that applying a herbicide in the fall of the year can be very advantageous to the producer. Herbicide applications made during the fall of the year reduce spring workloads and allow for earlier soybean planting (Krausz et al. 2003; Dahlke et al. 2001; Hasty et al. 2001). Fall herbicide applications can even reduce the need for a spring burndown to facilitate planting by eliminating winter annual weed populations. The elimination of winter annual weeds is currently the most popular reason for adopting fall herbicide applications.

Many winter annual weed species, such as henbit (*Lamium amplexicaule* L.), common chickweed [*Stellaria media* (L.) Vill.], and purple deadnettle (*Lamium purpureum* L.), appear to have increased in severity in recent years. Many have accredited this to the increased adoption of glyphosate-resistant crops and glyphosate usage, which has subsequently led to a reduction in the use of soil-applied residual herbicides. For example, in 1996, 43, 15, and 27% of the total U.S. soybean acreage received applications of imazethapyr, imazaquin, and pendimethalin, respectively (USDA 1997). However, in 2002 only 9% of the total U.S. soybean acreage received applications of imazethapyr and pendimethalin, while applications of imazaquin were applied on less than 1% of the total soybean acreage (USDA 2003). It has also been hypothesized that the relatively mild winters experienced over the past few years have favored the development of winter annual weeds (Güeli and Smeda 2001; Güeli and Smeda 2002; Krausz et al. 2003). The utilization of fall-applied herbicides to control these problematic winter annual weeds has proven to be effective (Lee et al. 2001; Loux and Dobbels 2001; and Sprague and Hager 2000). Though the effectiveness of fall-applied herbicides on winter annual weeds has been well documented, little research has been conducted on the effects of fall herbicide applications on other factors in the agroecosystem such as soil temperature, soil moisture, insect populations, and soybean cyst nematode (*Heterodera glycines* Ichinohe) populations.

Currently, there is only contradictory information available on the effects of the removal of winter annual weeds on soil temperature. A study conducted by Lee and Witt (2001) found that soil temperatures increased in plots where fall-applied atrazine or simazine was used to control henbit, while Krausz et al. (2003) reported that soil temperatures did not increase with the use of a fall-applied herbicide. Recent information released on the effect of winter annual weeds on soybean cyst nematode (SCN) populations contends that certain winter annual species like purple deadnettle, henbit, field pennycress (*Thlaspi arvense* L.), and sherperd's-purse [*Capsella bursa-pastoris* (L.) Medicus] can act as alternative hosts for SCN (Venkatesh et al. 2000). However, this has only been consistently determined in a greenhouse setting, while field studies have yielded varying results. There is even less information available on the effects of winter annual weed removal with fall herbicide applications on populations of various insect pests like the black cutworm [*Agrotis ipsilon* (Hufnagel)], corn flea beetle (*Chaetocnema pulicaria* Melsheimer), bean leaf beetle [*Cerotoma trifurcata* (Forster)], burrower bug

[*Sehirus cinctus cinctus* (Palisot de Beauvois)], and negro bug [*Corimelaena pulicaria* (Germar)].

INTRODUCTION

Winter Annual Weeds

An annual can be considered any type of plant which completes its entire life cycle in one year or less. Winter annuals are plants which germinate in the fall, produce seed in the spring, and die by midsummer. The seeds of winter annuals remain dormant in the soil throughout the summer. This dormancy is broken in the fall when soil and air temperatures decline and conditions for germination become optimal. Winter annual weeds have traditionally been considered major weed pests of winter grown crops such as winter wheat and barley (Monaco et al. 2002). Winter annual weeds are unable to complete their life cycles and compete with summer annual crops when some type of tillage is implemented before spring planting (Buhler and Owen 1997). Where no-tillage practices are utilized in corn and soybean production, however, winter annual weeds can interfere with spring planting and can actively compete with the developing crop (Krausz et al. 2003; Buhler 1995). Due to the development of dense canopies that often exist at the time of spring planting, winter annual weeds can also become very difficult to control with spring herbicide applications (Kapusta 1979; Wilson et al. 1985).

Conservation Tillage

Conservation tillage can be described as any tillage system which preserves at least 30% of the crop residue on the soil surface after planting (NRCS 2005). Conservation tillage is a broad category which can be further divided into three specific types of tillage.

These include no-till, mulch-till, and ridge-till. No-till can be considered any type of system which implements no preplant tillage, leaves the soil completely undisturbed except for planting, and utilizes herbicides for weed control (Buhler 1995). Mulch-till can be described as any type of conservation tillage system in which the entire soil surface is disturbed by a tillage tool, such as a field cultivator, disk, or chisel plow, just prior to or at planting (CTIC 2005). With ridge-tillage a ridge of soil is built by cultivation prior to planting, and at planting the soil from the ridge is moved to the interrow area (Buhler 1995).

Conservation tillage has many benefits such as reducing soil erosion, increasing organic matter, increasing soil moisture content, and improving water quality. These benefits, combined with improved weed control technology and increased efforts by the federal government to require soil conservation programs on highly erodible acres, have led to an increase in conservation tillage participation (Fawcett and Towery 2002). In 2000, over 36 percent of the total cropland in the United States participated in some type of conservation tillage system. The implementation of conservation tillage by farmers has led to a 30 percent reduction in sheet and rill erosion on cropland between 1982 and 1997. Sheet and rill erosion has been reduced from 9,856 kg/ha/year in 1982 to 6,944 kg/ha/year in 1997 (NRCS 2000). The utilization of no-till systems alone can reduce erosion by 90 percent (Hebblethwaite 1995). As a result, no-till adoption here in the U.S. has increased more than 200 percent from 1990 to 2002 (CTIC 2005).

No-till can offer another more obscure benefit besides reduction in soil erosion. When continuous no-till is utilized, it results in large amounts of crop residue remaining on the soil surface. This large amount of residue provides favorable habitats for natural insect enemies and thereby increases their diversity and abundance in no-till fields (Burton and Burd 1994). House and Stinner (1983) discovered that ground beetle or carabid (family Carabidae) diversity and abundance was higher in no-till soybean than in conventional soybean tillage systems. House and Alzugaray (1989) found that there was a higher number of carabid and staphylinid (family Staphylinidae) predators in no-till systems than in conventional ones. Even natural enemies that inhabit plant foliage, such as the minute pirate bug (*Orius* sp.), damsel bug (*Nabis* sp.), and big-eyed bug (*Geocoris* sp.) were found to be more abundant in no-till systems (Ferguson et al. 1984).

Although no-till is beneficial in increasing the abundance and diversity of predatory insects present in fields, it can also increase the intensity of weed pests such as winter annuals and biennials. Reduced soil disturbance in no-till fields provides a suitable environment for the establishment of many winter annual and biennial species. These weed species thrive in this environment because there is no tillage to disrupt their life cycles (Bazzaz 1990; Buhler 1995; Wicks et al. 1994). When tillage is implemented in the spring, winter annual and biennial species that became established in the fall are destroyed. However, when tillage is not utilized in the spring, winter annual species such as horseweed [*Conyza canadensis* (L.) Cronq.] can become quite prevalent. Brown and Whitewell (1988) evaluated the influence of tillage on horseweed and discovered that as tillage decreased, the establishment of horseweed increased. Horseweed can become well established in no-till fields because it produces many wind-blown seeds which germinate well when soil disturbance is reduced (Bhowmik and Bekech 1993). Horseweed is also favored by no-till because it can develop under a broad spectrum of climatic soil conditions (Fernald 1950), and is tolerant to many of the herbicides commonly used on no-till fields (Bruce and Kells 1990).

Many annual grasses are also well adapted to the no-till environment (Kapusta et al. 1993). The winter annual downy brome (*Bromus tectorum* L.) has been identified as a problematic weed in continuous winter wheat production maintained under conservation tillage (Moyer et al. 1994, Derksen et al. 2002). Downy brome thrives in this environment because its seeds germinate and grow well on the soil surface (Fay 1990). With no-till there is no disturbance of the soil surface or burial of the weed seed, so the downy brome seed is allowed to remain on the surface and germinate. Residue left on the soil surface due to no-till practices reduces evaporation of soil water, which produces favorable soil moisture conditions conducive to downy brome establishment. Blackshaw (1991) determined that downy brome germination drastically decreases when soil moisture levels fall below -1.03 Mpa.

Giant foxtail (*Setaria faberi* Herrm.), a summer annual, is another annual grass which has become problematic in no-till. As tillage is reduced, giant foxtail becomes more difficult to control (Buhler and Daniel 1988; Buhler and Oplinger 1990; Kapusta et al. 1993). Accumulation of giant foxtail seed near the soil surface in no-till fields leads to an increase in the overall emergence of giant foxtail (Stahl et al. 1999). Germination and emergence of giant foxtail seedlings from shallow depths in no-till is aided by crop residue, which increases moisture in the soil surface (Buhler and Mester 1991) and protects the young seedlings (Dao 1987; Hamrick 1987).

Winter Annual Weed Effects on Insects

Winter annual weeds can serve as alternative hosts for many insect pests of crop plants. One pest in particular, the black cutworm, benefits greatly from the presence of dense populations of winter annual weeds. The black cutworm was named in 1867 by CV Riley, who noted its detrimental effects on corn seedlings in the flood plains of the Mississippi and Missouri rivers (Showers 1997). It has since become a major pest of corn throughout the Midwest. Black cutworm larvae cause damage to seedling corn by severing plants off at the ground or chewing into stalks and roots. Black cutworm larvae are also capable of causing significant reductions in corn yield. A study by Santos and Shields (1998) encountered yield losses as high as 81% due to black cutworm damage. Many have attributed higher infestation levels of black cutworm larvae in fields to the presence of dense stands of winter annual weeds. The black cutworm is unable to overwinter in climates as far north as the Corn Belt (Story and Keaster 1982), therefore, moths must migrate into this area from southern states in early spring (Sherrod et al. 1979; Showers 1989a; Showers 1989b). This migration takes place prior to corn planting, so the moths must utilize alternative weed hosts as sites for food, shelter, and oviposition. Several winter annual weed species, such as common chickweed, henbit, shepherd's-purse, mouseear chickweed (*Cerastium vulgatum* L.), yellow rocket (*Barbarea vulgaris* R. Br.), Virginia pepperweed (*Lepidium virginicum* L.), and purslane speedwell (*Veronica peregrina* L.) are utilized by the moths as sites for oviposition (Busching and Turpin 1976; Cook and Nordby 2006; Johnson et al. 1984; Sherrod et al. 1979). These same weeds can then serve as a food source for the developing larvae. When this food source is removed from a developing corn field, the black cutworm larvae then begin feeding on the seedling corn. Therefore, the timing of winter annual weed removal can have a significant effect on the degree of damage caused by the black cutworm on developing corn plants. Showers et al. (1985) discovered that herbicide applications or tillage operations implemented 8 or 14 days before planting resulted in minimal corn seedling damage. Weed removal at this preplant interval caused larval starvation before the corn seedlings could act as an adequate host. In this same study they encountered maximum corn seedling damage when weeds were removed two days before planting or at planting through tillage operations, or when weeds were removed through herbicide applications two days before planting, at planting, and two days after planting. Larval starvation did not occur at these intervals closer to planting because the black cutworm larvae were provided with a new food source before their weed hosts were destroyed. Engelken et al. (1990) also concluded that preplant herbicides applied at least 14 days prior to planting in no-till situations would minimize black cutworm damage to corn seedlings and its effect on crop yield.

The corn earworm [*Helicoverpa zea* (Boddie)] is another major insect pest which benefits from the presence of winter annual weeds. Corn earworm can cause damage to many different cultivated crops including corn and soybean. Larvae cause damage to corn by feeding on the silks, which disrupts pollination and results in barren ears. Yield reductions to field corn caused by the corn earworm can range from five to seven percent (Boyd and Bailey 2001). Corn earworm larvae cause damage to soybean by feeding on the leaves, pods, and flowers. Eckel et al. (1992a, 1992b) reported that soybean yield was reduced due to flower and pod feeding by corn earworm larvae. They attributed yield losses to reductions in pod set and seed number.

In Missouri, the corn earworm overwinters as a pupa in the soil. In April, corn earworm moths emerge from the soil and females begin ovipositing their eggs on host plants. Female moths are capable of ovipositing 350 to 3,000 eggs on a single host plant (Pedigo 2002). It has been discovered that corn earworm moths are capable of utilizing many wild host plants as sites for oviposition. These species are primarily weed hosts, such as black medic (*Medicago lupulina* L.), dovefoot geranium (*Geranium molle* L.), and even the winter annual common mallow (*Malva neglecta* Wallr.) (Sudbrink & Grant 1995). A recent study conducted by Esquivel (2004) suggests that henbit can also serve as a host for corn earworm oviposition. Henbit is a major winter annual weed of no-till fields and is capable of forming dense populations. If henbit is able to act as a host for corn earworm, then dense stands left uncontrolled until planting could increase the population and infestation level of corn earworm present in the field.

Winter Annual Weed Effects on SCN

Soybean cyst nematode was first discovered in the U.S. in North Carolina in 1954. It has since become a damaging pest of soybean stretching across most of the U.S. causing nearly $840 million in soybean crop loss (Wrather 2006). A survey conducted by Workneh et al. (1999) concluded that 47 to 83% of soybean hectarage in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ohio was infested with SCN. Soybean cyst nematode causes more soybean yield losses than any other disease (Wrather et al. 2001; Wrather et al. 2003; Wrather and Koenning 2006). Estimated soybean yield reductions due to soybean cyst nematode were over 3.5 million metric tons in the U.S. in 2004 (Wrather and Koenning 2006).

The SCN life cycle includes three stages (egg, juvenile, and adult) and is typically completed in 24 to 30 days. Infection takes place when juveniles use their stylet to penetrate the soybean root. After penetration, they move to vascular tissue and inject secretions onto root cells to transfer them into specialized feeding sites. These specialized feeding sites allow the nematode to feed on cellular material and interfere with nutrient and water uptake by the plant. The severity of SCN infection on soybean yield loss is highly dependent on the population density of SCN present in the field, and on the type of soybean cultivar grown. Niblack et al. (1992) reported that yields were reduced by up to 52% when susceptible soybean cultivars were grown in plots infested with 1,250 eggs per 100 cm^3. Alston et al. (1993) discovered that SCN populations categorized into three different densities, low, medium, and high, caused yield reductions of 12, 22, and 30%, respectively. Yield losses of up to 100% can occur in areas of a field heavily infested with SCN (Riggs and Schmitt 1987).

Though soybean is the preferred host of SCN, several other plant species, including many weed species, can act as alternative hosts for SCN. Riggs and Hamblen (1962, 1966) determined that SCN has a wide host range which extends across weed species of 23 plant families. Past studies have implicated henbit and common chickweed as alternative hosts for SCN (Epps and Chambers 1958; Riggs and Hamblen 1966), but a recent greenhouse experiment conducted by Venkatesh et al. (2000) identifies purple deadnettle, field pennycress, and shepherd’s-purse as other winter annual weed hosts. Creech et al. (2005) have also recently confirmed the ability of SCN to reproduce on purple deadnettle under field conditions. Many researchers have suggested that this could have severe implications on SCN populations in no-till fields, as the presence of winter annual weeds early and late in the growing season could provide a means for SCN reproduction while soybeans are absent. Levene et al. (1998) determined that the application of the herbicides acifluorfen, bentazon, and lactofen to remove weed hosts led to a 50 to 60% reduction in SCN egg populations. However, Johnson and Creech (2005) and Nelson et al. (2003) observed no significant differences in SCN populations for fall or spring herbicide weed management systems when compared to the untreated control. Harrison et al. (2002) also observed no significant differences in SCN populations with the removal of purple deadnettle throughout the fall or spring.

Influence of Winter Annual Weeds on Soil Conditions

Soil temperature and moisture are two factors which greatly influence the germination and emergence of annual weeds. The temperature and moisture requirements of these weeds in relation to those of the crop will determine their subsequent level of competition with the crop. Blackshaw et al. (1981) determined that green foxtail (*Setaria viridis*) germination and emergence were delayed when the soil was allowed to dry to -4.0 to -6.5 bars. They noted optimum germination of green foxtail when the soil was moist at 0 to -4.0 bars. In a study testing 17 weed and five crop species, Hoveland and Buchanan (1973) concluded that most weed seed needed more moisture for germination than crop seed. For this reason, many researchers have advocated the use of fall-applied herbicides in no-till situations. They contend that fall herbicide applications, which remove winter annual weeds, will increase soil temperatures and accelerate soil drying early in the spring thereby providing conditions conducive to crop emergence and discouraging to overall weed emergence. Increased soil temperatures and accelerated soil drying also facilitates planting, which allows producers to plant their crops earlier and obtain maximum photosynthetic capabilities (Dahlke et al. 2001; Krausz et al. 2003; Lee and Witt 2001; Martin et al. 2002).

Studies conducted by Lee and Witt (2001) and Martin et al. (2002) determined that the application of herbicides in the fall to remove winter annual weeds led to increased soil temperatures during the spring planting season. However, Krausz et al. (2003) observed no significant differences in soil temperatures at a 5 cm depth between fall herbicide applications and spring-applied herbicide treatments. Similarly, Güeli and Smeda (2004) determined that soil temperatures at a 10 cm depth did not increase with the utilization of a fall herbicide application.

Fall-applied Herbicide Efficacy

Fall-applied herbicides vary greatly in their effectiveness at controlling winter annual weeds and providing residual control of emerging summer annual weed species. This level of variability is quite evident with many of the corn herbicides applied in the fall. Young et al. (2003) reported that fall applications of simazine at 1.12 kg ai/ha provided 83% control of common ragweed (*Ambrosia artemisiifolia* L.) at planting, but only 63% control of giant foxtail at planting. This is similar to other findings by Young et al. (2002), who reported 80% control of common ragweed and only 50% control of giant foxtail at planting with fall applications of simazine at 1.12 kg ai/ha. Young et al. (2002) also reported that control of these same weeds with fall applications of rimsulfuron (0.017 kg ai/ha) plus thifensulfuron (0.009 kg ai/ha) was less than 50% at planting. Lee and Witt (2001) reported similar findings in regards to summer annual weed control. They obtained no suppression of summer annual weed populations with fall applications of atrazine at 1.7 kg ai/ha and simazine at 1.7 kg ai/ha.

Krausz et al. (2003) reported more favorable control of several winter annual weed species with various fall herbicide applications. They obtained greater than 96% control of Carolina foxtail (*Alopercurus carolinianus* Walt.) and mouseear chickweed with applications of atrazine at 1.12 kg ai/ha, simazine at 1.12 kg ai/ha, and rimsulfuron plus thifensulfuron at 0.017 kg ai/ha plus 0.009 kg ai/ha. Control of henbit was 92% with applications of simazine, while its control increased to 97% with applications of atrazine and rimsulfuron plus thifensulfuron. All three of these treatments did, however, provide poor control of wild garlic at planting. Similarly, Lee and Witt (2001) obtained excellent control of henbit with fall applications of atrazine and simazine, but reported less than 59% control of wild garlic with these same two herbicide treatments.

Many researchers have also focused on the effects of non-residual fall herbicide applications on winter annual weeds and the effect of their removal on emerging summer annual weeds. Hasty et al. (2004) reported that fall applications of glyphosate plus 2,4-D at 0.628 kg ae/ha plus 0.28 kg ai/ha provided effective control of common chickweed, henbit, and shepherd’s-purse. However, this fall treatment had no control on summer annuals such as giant ragweed (*Ambrosia trifida* L.), common ragweed, common lambsquarters (*Chenopodium album* L.), and common waterhemp (*Amaranthus rudis* Sauer). Güeli and Smeda (2004) obtained similar results with fall applications of glyphosate plus 2,4-D at 0.84 kg ae/ha plus 0.56 kg ai/ha. They reported greater than 94% control of common chickweed and henbit, and greater than 80% control of downy brome with the non-residual treatment. In contrast, they obtained inconsistent control of common ragweed and giant foxtail with the fall treatment.

Fall applications of non-residual broad-spectrum herbicides such as glyphosate provide excellent control of many winter annual weed species present at the time of application. However, the elimination of existing winter annual weeds and the lack of residual control provides an environment conducive to summer annual weed emergence in the spring, thereby requiring another burndown treatment before planting (Hasty et al. 2004; Güeli and Smeda 2004).

Applications of sulfentrazone plus chlorimuron have been one of the most popular fall herbicide programs in no-till soybeans throughout the Midwest. It provides excellent control of many winter annual weed species such as smallflowered bittercress (*Cardamine parviflora* L.), henbit, purple deadnettle, and cressleaf groundsel (*Senecio glabellus* Poir.). It also provides some control of early-emerging summer annuals like common lambsquarters and common waterhemp (Hasty et al. 2004). However, control of later-emerging summer annuals like giant foxtail is somewhat limited with this prepackaged combination (Güeli and Smeda 2001; Young and Krausz 2001b).

A premix of sulfentrazone plus chlorimuron has been sold by Dupont under the trade name Canopy XL® since 1997. The sulfentrazone component of this product makes it quite persistent in the soil having a half-life of 121 to 302 days (Vencill 2002a). In 2004 Canopy XL® was discontinued, and Dupont elected to replace it with a premix of tribenuron plus chlorimuron, which is sold under the trade name Canopy EX®. As opposed to Canopy XL®, fall applications of Canopy EX® provide excellent control of common chickweed. It also provides sufficient control of henbit and horseweed (Schmidt et al. 2001; Young and Krausz 2001a). However, due to the absence of sulfentrazone in Canopy EX®, this product lacks the persistent residual control obtained with applications of Canopy XL®. Tribenuron only has a soil half-life of 10 days as opposed to the 121 to 302 day half-life of sulfentrazone (Vencill 2002b). One would expect fall applications of tribenuron plus chlorimuron to have little effect on later-emerging summer annual weeds like common waterhemp in comparison to sulfentrazone plus chlorimuron. However, few studies have examined this in detail.

Summary and Objectives

Current agronomic practices utilizing no-till production systems and glyphosate resistant crops seem to provide conditions conducive to winter annual weed infestations. This, coupled with the ability to better distribute workloads, has led many producers throughout the Midwest to implement fall herbicide applications. Several studies have investigated the control of winter annual weed populations with fall-applied herbicides. However, few studies have investigated the effects of fall-applied herbicides on summer annual weed seedling emergence. Similarly, little information is available on the possible impacts that fall herbicide applications may have on other components of the agroecosystem. Therefore, the objectives of this research are to: 1) evaluate the efficacy of fall versus spring applications of herbicides on winter annual weed populations and the emergence of summer annual weed seedlings in both no-till corn and soybean, 2) determine the effects of fall and spring herbicide applications on soil temperature, soil moisture, and insect populations in no-till corn and soybean, and 3) evaluate differences in weed control obtained with residual and non-residual herbicide applications.

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CHAPTER II

Impact of Fall and Early Spring Herbicide Applications on Insect Populations and Soil Conditions in No-Till Soybean[1]

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Abstract: Fall herbicide applications have increased in popularity in recent years, yet little is known of how these applications affect various agronomic factors. Field studies were established at three Missouri locations in 2004 and 2005 to evaluate the effects of fall and early spring herbicide applications on soil temperature, soil moisture content, and insect populations in no-till soybean production systems. All three experiments received applications of chlorimuron plus sulfentrazone plus 2,4-D, chlorimuron plus tribenuron plus 2,4-D, and glyphosate plus 2,4-D in the fall, 60 days prior to planting (60 days EPP), 30 days prior to planting (30 days EPP), and seven days prior to planting (7 days EPP). During a period from April 1 to May 31, chlorimuron plus sulfentrazone plus 2,4-D applied 60 days EPP resulted in an increase in soil temperatures at a 2.5 cm depth compared to the untreated control when soil temperatures were above 20 C. However, differences in soil temperature were inconsistent when temperatures fell below 20 C. Significant treatment differences in the percent volumetric soil moisture content were

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present at two weeks before planting (WBP) and two weeks after planting (WAP). Two WBP, soil moisture in the untreated averaged 46.0% volumetric soil moisture content, while the herbicide treated plots ranged from 48.8% to 50.8%. Two WAP, the untreated averaged approximately 5.0% less soil moisture than any of the herbicide treatments. Shake-cloth samples taken at five and seven WAP revealed significantly higher numbers of total insects per 0.8 m^2 in the untreated compared to the herbicide treated plots. At five WAP, the untreated averaged 13 total insects per 0.8 m^2, while the herbicide treated plots ranged from one to two total insects per 0.8 m^2. Seven WAP the untreated averaged almost 19 total insects per 0.8 m^2 while the herbicide treated plots averaged only two to three total insects per 0.8 m^2. These drastic differences can be attributed to high negro bug [*Corimelaena pulicaria* (Germar)] densities in the untreated plots. Fall and early spring herbicide applications have limited value in accelerating the soil warming and drying process in the spring. However, these applications can reduce insect pest populations well after planting.

Nomenclature: Chlorimuron; glyphosate; sulfentrazone; tribenuron; 2,4-D; soybean, *Glycine max* (L.) Merr. 'Dekalb 38-52'.

Additional index words: *Corimelaena pulicaria*, fall herbicide applications, herbicide application timing, negro bug, no-till, soil moisture, soil temperature, weed-insect interactions, winter annuals.

Abbreviations: Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; EPP, early preplant; glyph, glyphosate; untr, untreated; WAP, weeks after planting; WBP, weeks before planting.

INTRODUCTION

Adoption of conservation tillage in the United States has progressively increased from 28 million hectares in 1990 to 45 million hectares in 2004. No-till soybean production alone has experienced a 200 percent increase in the period from 1990 to 2002 (CTIC 2005). Within no-till production systems, herbicide applications are solely relied upon for weed control. However, herbicide applications are traditionally delayed until shortly before or at planting. This type of weed control regime provides a favorable environment for winter annual weed establishment. Winter annual weeds left uncontrolled until spring planting can interfere with planting equipment and can become difficult to control with herbicides (Buhler 1995; Kapusta 1979; Wilson et al. 1985). Applications of residual herbicides in the fall can provide acceptable control of many winter annual weeds, and may even eliminate the need for a burndown application prior to planting (Hasty et al. 2004; Krausz et al. 2003). However, the benefits of fall herbicide applications may reach beyond weed control.

Many researchers believe that applying a residual herbicide in the fall can lead to more favorable soil conditions in the spring. They contend that removing winter annual weeds in the fall accelerates soil drying and warming in the spring (Dahlke et al. 2001; Kremer 2005). Lee and Witt (2001) reported that fall applications of atrazine and simazine led to warmer soil surface temperatures in the spring when compared to an untreated control. However, Krausz et al. (2003) observed no significant differences in soil temperatures at a 5 cm depth between plots treated with a herbicide in the fall and plots left untreated.

Though there is only contradictory information available on the effects of fall herbicide applications on soil temperature, there is little to no data available on the effects of fall-applied herbicides on soil moisture. Many believe that the absence of winter annual weeds in the spring will enable soils to dry faster. However, there is little information available to support this conclusion. In a study testing 17 weed and five crop species, Hoveland and Buchanan (1973) concluded that most weed seed required more moisture for germination than crop seed. If fall herbicide applications enabled soils to dry faster in the spring, they would not only facilitate earlier soybean planting, but also provide an environment conducive to crop emergence and discouraging to overall weed emergence.

Fall herbicide applications may also influence the incidence of insect pests present in no-till soybean production fields. Jones and Sullivan (1982) reported that the brown stink bug [*Euschistus servus* (Say)] could feed on Virginia pepperweed (*Lepidium virginicum* L.), a winter annual, in the absence of soybean. Similarly, the two-spotted spider mite [*Tetranychus urticae* (Koch)] can exist in high densities on henbit (*Lamium amplexicaule* L.), common chickweed [*Stellaria media* (L.) Vill.], and Carolina geranium (*Geranium carolinianum* L.) (Norris and Kogan 2000). This could provide a reservoir of two-spotted spider mites for later soybean infestation. Recent field observations suggest that the burrower bug [*Sehirus cinctus cinctus* (Palisot de Beauvois)], an occasional pest of soybean, is also affected by the presence of winter annual weeds. Severe burrower bug infestations have been associated with dense stands of henbit left uncontrolled until planting (Bailey 2004; Cook 2005). Herbicides applied in the fall to remove winter annual weeds such as henbit, Virginia pepperweed, common chickweed, and Carolina geranium may lead to a decrease in insect pest densities. However, removal of winter annual weeds may also influence beneficial insect populations.

Speight and Lawton (1976) determined that ground beetle (Coleoptera: Carabidae) density was directly related to annual bluegrass (*Poa annua* L.) density. As the amount of annual bluegrass present increases, so do carabid populations. Aphidophagous syrphids (Diptera: Syrphidae) and green lacewings [*Chrysoperla carnea* (Stephens)], natural enemies of aphids, can also benefit from the presence of winter annual weeds. Common chickweed, field pennycress (*Thlaspi arvense* L.), and purple deadnettle (*Lamium purpureum* L.) are important for the early establishment of aphidophagous syrphids, while purple deadnettle and shepherd's-purse (*Capsella bursa-pastoris* L.) can serve as oviposition sites for the green lacewing [*Chrysoperla carnea* (Stephens)] (Nentwig 1998). Removal of winter annual weeds through the use of fall-applied herbicides may not only decrease insect pest populations, but may also decrease beneficial insect populations.

Fall herbicide applications enable producers to spread out their spring workloads, and may even eliminate the need for a spring burndown application prior to planting (Hasty et al. 2004; Krausz et al. 2003). These are the primary reasons why fall herbicide applications have increased in popularity in recent years. However, there is little information available on the effect of fall and spring herbicide applications on soil temperature and soil moisture. There is also limited information available on the effects of winter annual weed removal through fall herbicide applications on insect populations in soybean. Therefore, the objectives of these experiments were to 1) determine the impact of fall and early spring herbicide applications on soil temperature and moisture and 2) to evaluate the effects of fall and early spring herbicide applications on insect populations in no-till soybean.

MATERIALS AND METHODS

Field experiments were established at three locations in Missouri in the fall of 2004 and 2005. One site was located in central Missouri at the University of Missouri Bradford Research and Extension Center, another site was located in northwest Missouri near St. Joseph, and the third site was located in northeast Missouri near Palmyra. Sites were selected based on the presence of corn residue and dense infestations of winter annual weeds. The soil type at the central Missouri location was a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs) with 2.4% organic matter and pH of 6.3 in 2004. In 2005 this site had a pH of 6.4 with 3.0% organic matter. At the northwest site in 2004 the soil type was a Monona silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls) with 2.3% organic matter and pH of 6.0. The soil type at this location in 2005 was a Colo silty clay loam (fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) with 2.0% organic matter and pH of 6.7. At the northeast location the soil type was Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) with 2.0% organic matter and pH of 6.2 in 2004. In 2005 this site had a pH of 5.9 with 3.3% organic matter.

In all experiments, the experimental design consisted of a randomized complete block with a factorial arrangement of four treatments and four application timings, and four replications. All plots were 6 by 14 m in size. The four treatments consisted of chlorimuron plus sulfentrazone plus 2,4-D at 23 plus 115 plus 542 g ai/ha, chlorimuron plus tribenuron plus 2,4-D at 35 plus 11 plus 542 g ai/ha, glyphosate plus 2,4-D at 1120 g ae/ha plus 542 g ai/ha, and an untreated control. All three herbicide treatments were applied at four different timings: fall (mid-November), 60 days EPP (early March), 30 days EPP (early April), and seven days EPP (late April). Detailed application information is listed in Table 2.1. Additionally, specific precipitation and air temperature information is listed in Tables 2.2 and 2.3. Treatments consisting of chlorimuron plus sulfentrazone and chlorimuron plus tribenuron received crop oil concentrate[3] at 1% v/v. Treatments containing glyphosate received ammonium sulfate at 2.9 kg/ha.

All herbicide applications were made with a CO_2 backpack sprayer set to deliver 140 L/ha at 124 kPa through XR8002[4] flat fan nozzles. Seven WAP a post application of glyphosate at 1260 g ae/ha with 2.9 kg/ha of ammonium sulfate was broadcast over each trial with a tractor-mounted sprayer.

At all locations, Dekalb '38-52' glyphosate-resistant soybean was planted in early to mid-May into a no-tillage seedbed which was planted to corn the previous year. Seed was planted in 76 cm rows at a density of 395,000 seeds/ha.

Soil Moisture. Soil moisture measurements were taken at bi-weekly intervals beginning in early March and continuing until two WAP. A Field Scout TDR 300 Soil Moisture Probe[5] was used to measure and record the percent volumetric water content within the soil. Four random measurements were taken in each plot at a depth of 12 cm resulting in a total of 16 measurements of soil moisture per treatment. On the day of sampling, soil moisture measurements were taken between the hours of 10:00 a.m. and 3:00 p.m.

Soil Temperature. Evaluations of soil temperature were not made in 2005, but were conducted at all three locations in 2006. Soil temperature measurements were recorded

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[3] Relay brand crop oil concentrate, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

[4] Teejet Spraying Systems Co, North Avenue, Wheaton, IL 60189.

[5] Spectrum Technologies, Inc., 12360 South Industrial Drive, Plainfield, IL 60585.

with Hobo Pro Temp Data Loggers[6] inserted to a depth of 2.5 cm. These thermometers logged the soil temperature each day at 12:00 p.m. Thermometers were only placed within the 60 days EPP application timing of chlorimuron plus sulfentrazone plus 2,4-D and the untreated control treatments. Thermometers were placed within these plots in order to evaluate differences in soil temperature between our most weed-free treatment and untreated. One thermometer was randomly placed within each plot of the previous two treatments for a total of four thermometers per treatment at each location. Measurements of soil temperature began in early March and continued until late June.

Insects. Insect populations were monitored at the central location in 2005 and 2006 by taking two random shake-cloth samples from each plot at bi-weekly intervals beginning when the soybeans reached the V1 stage of growth (equivalent to three WAP) and ending seven WAP. Each sample consisted of two adjacent rows of soybean plants shaken over a white vinyl Ground Cloth[7] that was 107 cm in length and 76 cm wide (0.8 m^2). In essence, each sample consisted of 214 cm of soybean row. After collection, samples were put into sealable plastic bags and placed in a freezer for storage. Samples were then removed from the freezer at a later date and the number of insects per species was recorded for each sample. Insect sampling was conducted between the hours of 10:00 a.m. and 12:00 p.m. on each sampling date.

Data analysis. All data were analyzed using the Proc Mixed procedure in SAS (2005). As suggested by Carmer et al. (1989), each year-location combination was considered an environment sampled at random. For soil moisture data, fixed effects in the model were herbicide treatment and application timing. Random effects included environment,

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[6] Onset Computer Corporation, 470 MacArthur Boulevard, Bourne, MA 02532.

[7] Great Lakes IPM Inc., 10220 Church Road, Vestaburg, MI 48891.

replications (nested within environments), and all interactions with environment and replications. Soil temperature data were analyzed using replication and replication by location interactions as random effects, while treatment was used as a fixed effect. For insect sampling data, replication and replication by year interactions were used as random effects, and herbicide treatment and application timing were used as fixed effects. Considering environments at random enables inferences about the treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003; Hasty et al. 2004). Individual treatment differences were detected by using Fisher's protected LSD at $P < 0.05$. Nontransformed means are presented because transformations did not alter the data interpretation.

RESULTS AND DISCUSSION

Soil Moisture. Treatment by application timing interactions were not significant, therefore, treatment means were averaged across timings to display significant differences in treatments (Figure 2.1). At four WBP, there were no significant differences in the percent volumetric soil moisture for any of the treatments. Treatments ranged from 49.9% to 50.8% volumetric soil moisture. However, two WBP the untreated control plots had a significantly lower soil moisture percentage than any of the herbicide treated plots. Soil moisture in the untreated averaged 46.0% while the herbicide treated plots ranged from 48.8% to 49.6%. There was also a significant effect of application timing at this sampling date only. The seven day EPP treatments averaged approximately 2.0% lower soil moisture than the other three application timings (data not shown). This soil moisture deficit mirrors the deficit expressed in the untreated plots on this same date.

At two WBP the seven day EPP treatments had not been applied, and were therefore similar to untreated controls. Differences in soil moisture between treatments at planting were negligible. It is likely that significant rainfall events just prior to planting at most of the locations negated any treatment differences. However, at two WAP there was once again a significant difference in the percent volumetric soil moisture between the herbicide treated and untreated plots. The untreated control had approximately 5.0% less soil moisture than any of the herbicide treatments. In general, the percent volumetric soil moisture content on this date was lower for all four treatments when compared with earlier dates. Collectively, the data indicate that as the percent volumetric soil moisture content approaches 50% any potential differences between the herbicide treated and untreated plots become negligible. However, when this measurement falls below 50%, differences between the untreated control and herbicide treatments become amplified.

Soil Temperature. Plots receiving applications of chlorimuron plus sulfentrazone plus 2,4-D at 60 days EPP had soil temperatures ranging from 4 C higher to -1 C lower than the untreated control within each day (Figure 2.2). Differences in soil temperature were variable below 20 C. In early April when soil temperatures were gradually increasing to 20 C the chlorimuron plus sulfentrazone plus 2,4-D treatment consistently had a higher soil temperature than the untreated. However, when there were sudden decreases in temperature (below 20 C) in late April to mid-May these differences were negated. When temperatures remained above 20 C, the chlorimuron plus sulfentrazone plus 2,4-D treatment consistently resulted in higher soil temperatures than untreated plots with a dense cover of winter annual weeds. Temperature fluctuations did not appear to be effected by herbicide application. Both the chlorimuron plus sulfentrazone plus 2,4-D plots and the untreated control appeared to have similar fluctuations in temperature.

Insects. Interactions between application timing and herbicide treatment were absent in all three sampling dates, therefore, treatments means were averaged across timings. At three WAP, very few differences between treatments were detected. The only difference that did occur was in the total number of insects per treatment. Here, the untreated averaged five total insects per 0.8 m^2, while the herbicide treated plots ranged from zero to one insect per 0.8 m^2 (data not shown). At five WAP, however, the difference between the untreated and herbicide treated plots drastically increased. At this date the untreated averaged 13 total insects per 0.8 m^2, while the herbicide treated plots ranged from one to two total insects per 0.8 m^2 (Figure 2.3). This drastic difference can be attributed to the negro bug population in each of the treatments. The herbicide treated plots averaged only as high as one negro bug per 0.8 m^2, while the untreated contained approximately 10 negro bugs per 0.8 m^2. This same trend can also be seen at the seven WAP date. At this date the untreated averaged 16 more insects per 0.8 m^2 than any of the herbicide treatments (Figure 2.3). Once again this was primarily due to the high number of negro bugs present in the untreated plots. Negro bugs alone made up approximately 70% of the total number of insects present in the untreated plots.

Field observations revealed that the high number of negro bugs present at the five and seven WAP dates can be directly correlated with the presence and abundance of annual fleabane [*Erigeron annuus* (L.) Pers.] on these same dates. On both of these dates annual fleabane was only present in the untreated plots and was in the flowering stage of growth. Negro bugs could be seen feeding in high densities on the flower heads of annual fleabane on both dates. This suggests that negro bug densities are positively correlated with winter annual weed densities. This information could be important for controlling populations of negro bugs, an emerging pest of no-till soybean production in Missouri (W. C. Bailey, personal communication).

Overall, an early spring treatment of chlorimuron plus sulfentrazone plus 2,4-D did increase soil temperatures compared to a untreated control. This is contradictory to the findings of Krausz et al. (2003). However, it appears that the increased temperature benefits are only consistently present when soil temperatures exceed 20 C. At these higher temperatures, the presence of dense stands of winter annual weeds in the untreated plots may have a shading effect, which slows the soil warming process. When temperatures fall below 20 C, however, this shading effect becomes unnoticeable. Herbicide application timing had little to no effect on soil moisture at the four sampling dates (four WBP, two WBP, at planting, and two WAP). Though herbicide treatment had no effect on soil moisture at planting, it did lead to higher soil moisture contents two WAP in these experiments. In general, winter annual weeds do not appear to have a significant impact on the percent volumetric soil moisture content until these values fall below 50%. When this occurs it appears that winter annual weeds can cause significant reductions in soil moisture. Removing winter annual weeds through a herbicide application in the fall or spring can also lead to significant reductions in negro bug and total insect populations five and seven WAP. Based on the results of this study, applying a herbicide in the fall or early spring to increase soil temperatures and drying before planting may provide limited value. However, making fall or early spring herbicide applications can lead to lower insect populations well after planting.

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Table 2.1. Herbicide application and planting information for the central, northwest, and northeast Missouri field experiments conducted in 2004-2005 and 2005-2006.

	Central		Northwest		Northeast	
	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006
Application dates						
Fall	November 12	November 4	November 22	November 10	November 23	November 21
60 EPP	March 3	February 28	March 14	March 2	March 4	March 7
30 EPP	April 6	April 4	April 13	March 28	April 1	April 4
7 EPP	May 3	April 25	May 9	April 27	April 25	May 2
Soil temperature at application[a]						
Fall	14.4	11.1	8.9	9.4	10.2	6.1
60 EPP	8.3	10.6	5.6	4.4	5.9	3.9
30 EPP	11.7	16.1	11.7	4.4	13.3	10.6
7 EPP	11.7	12.2	17.8	8.9	9.4	11.1
Planting dates	May 17	May 8	May 23	May 15	May 3	May 10

[a]Soil temperature in degrees Celsius taken at a 5 cm depth.

Table 2.2. Precipitation from March through July at the central, northwest, and northeast Missouri locations in 2005 and 2006.

	Central		Northwest		Northeast	
	2005	2006	2005	2006	2005	2006
	------------------------	------------------------	------------------------	mm	------------------------	------------------------
Month						
March	24	92	19	54	25	89
April	92	52	80	115	55	52
May	78	81	115	42	38	33
June	91	96	165	72	57	110
July	11	77	30	98	22	58
Total[a]	296	398	409	381	197	342

[a]Total rainfall from March 1 to July 31.

Table 2.3. Maximum and minimum air temperature from March through July at the central, northwest, and northeast Missouri locations in 2005 and 2006.

	Central				Northwest				Northeast			
	2005		2006		2005		2006		2005		2006	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
	------C------											
Month												
March	26	-7	25	-5	23	-9	24	-6	25	-7	26	-9
April	27	-1	31	0	26	-1	32	0	28	-1	31	-2
May	30	1	32	6	31	0	33	6	30	-1	34	4
June	34	14	32	13	34	14	34	13	36	11	33	12
July	39	14	38	14	36	13	37	15	41	12	38	13

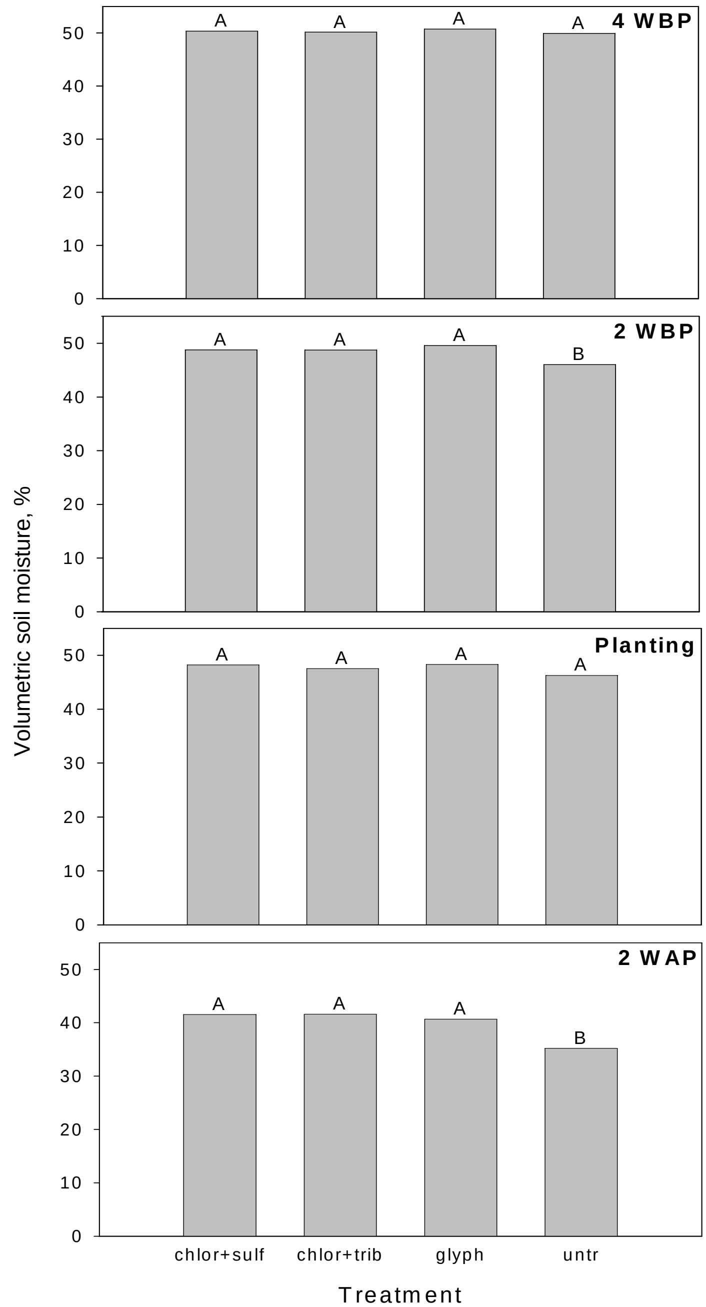

Figure 2.1. Influence of fall and early spring herbicide applications on the percent volumetric soil moisture content at all six environments four weeks before planting (4 WBP), two weeks before planting (2 WBP), at planting (Planting), and two weeks after planting (2 WAP). Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; glyph, glyphosate; untr, untreated. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment by timing interactions were not significant, therefore, treatment means were averaged across timings. Treatment means with different upper-case letters are significantly different at the 0.05 level of significance.

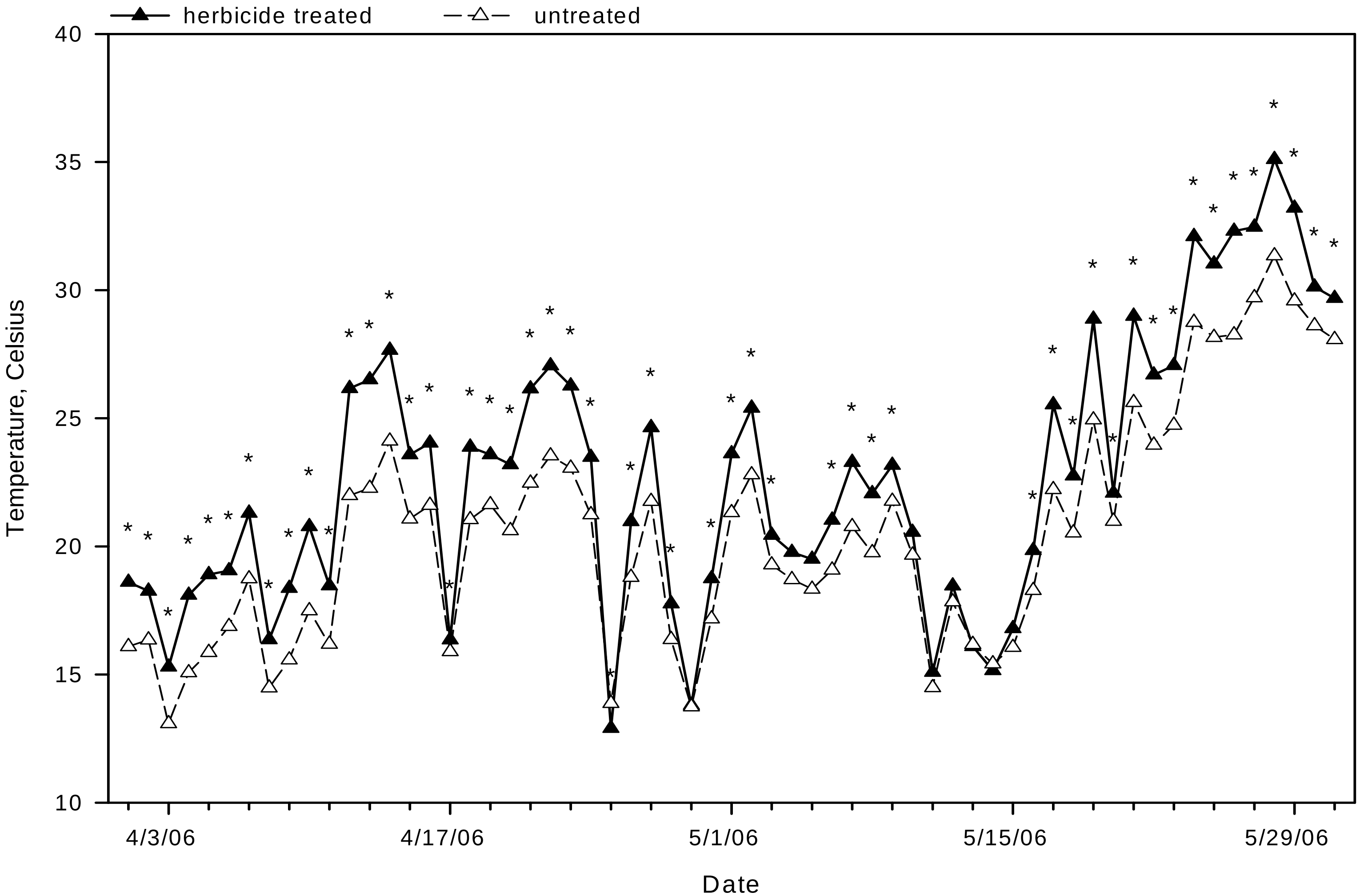

Figure 2.2. Comparison of herbicide treated (chlorimuron+sulfentrazone+2,4-D) and non-treated (untreated) soil temperatures from all three locations. Measurements began on April 1, 2006 and ended May 31, 2006. Asterisks indicate significant differences ($P < 0.05$) in soil temperature when compared within each day.

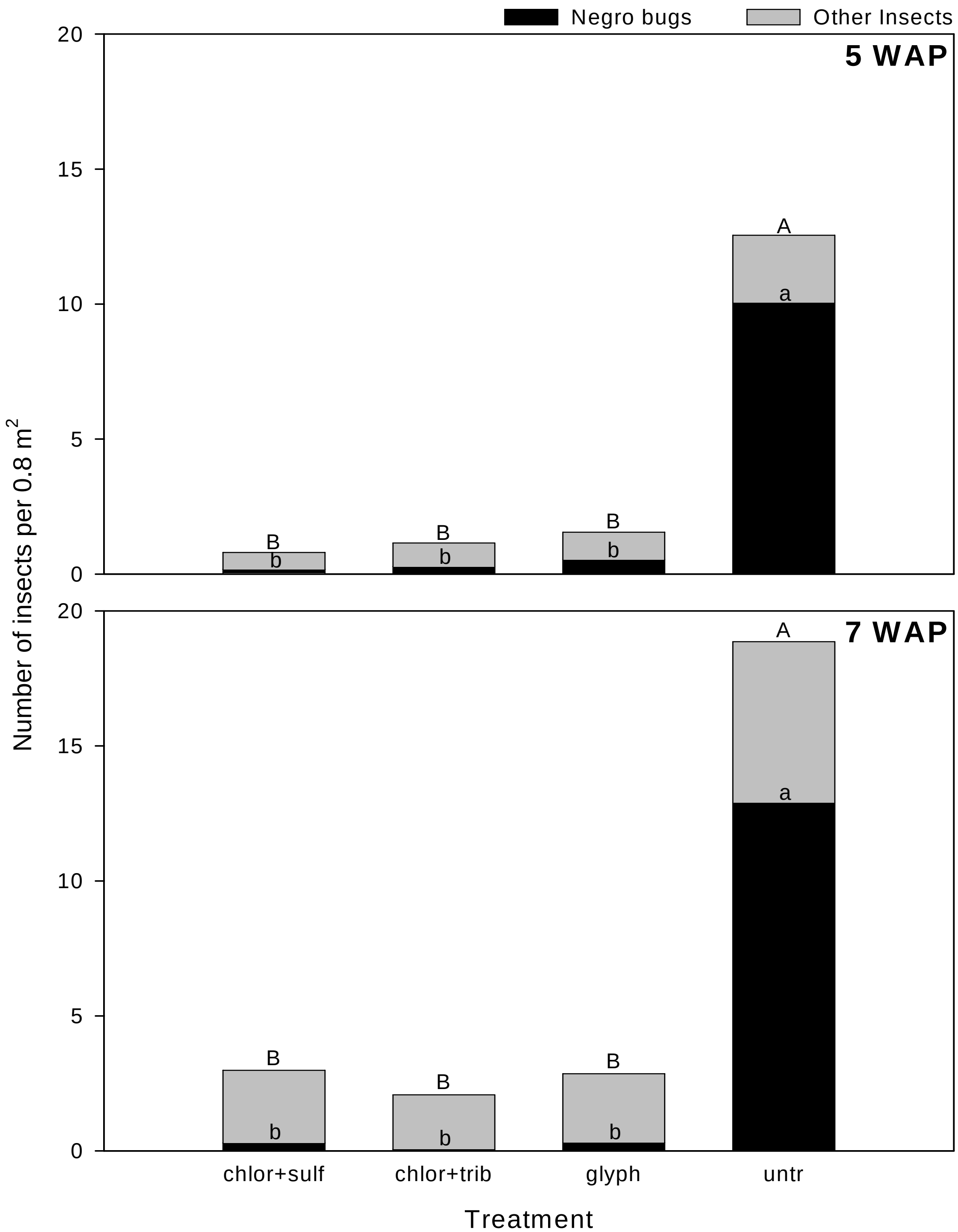

Figure 2.3. Impact of fall and spring herbicide applications on negro bug (*Corimelaena pulicaria*) and total insect (Negro Bugs plus Other Insects) populations per 0.8 m^2, five and seven weeks after planting (5 WAP, 7WAP) at the central location in 2005 and 2006. Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; glyph, glyphosate; untr, untreated. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment by timing interactions were not significant, therefore, treatment means were averaged across timings. Treatment means with different upper-case letters indicate significant differences ($P < 0.05$) in total insect populations. Treatment means with different lower-case letters indicate significant differences ($P < 0.05$) in negro bug populations.

CHAPTER III

Influence of Fall and Early Spring Herbicide Applications on Winter and Summer Annual Weed Populations in No-Till Soybean[1]

NICHOLAS MONNIG and KEVIN W. BRADLEY[2]

Abstract: Recent trends in agricultural practices have led to an increase in winter annual weed infestations. Field trials were initiated at three Missouri locations in the fall of 2004 and 2005 to compare the efficacy of fall and early spring herbicide applications on winter and summer annual weed populations in no-till soybean. All three experiments received applications of chlorimuron plus sulfentrazone plus 2,4-D, chlorimuron plus tribenuron plus 2,4-D, and glyphosate plus 2,4-D in the fall, 60 days prior to planting (60 days EPP), 30 days prior to planting (30 days EPP), and seven days prior to planting (7 days EPP). Weed control ratings conducted at planting revealed greater than 97% control of all winter annuals, except common chickweed, from fall applications of chlorimuron plus sulfentrazone plus 2,4-D and chlorimuron plus tribenuron plus 2,4-D. Fall, 60 day EPP, and 30 day EPP applications of chlorimuron plus sulfentrazone plus 2,4-D provided less than 69% control of common chickweed. Glyphosate plus 2,4-D applied in the fall and 60 days EPP provided adequate control of early fall germinating winter annuals, such as common chickweed and henbit. However, these treatments resulted in poor control of winter annual species which exhibited some degree of spring germination. Control of

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summer annual weed species seven weeks after planting (WAP) was highly variable. Relatively poor control of common waterhemp was obtained from all treatments except chlorimuron plus sulfentrazone plus 2,4-D applied at all three spring timings. Giant foxtail control was highly variable ranging from 0 to 95% control. Measurements of weed biomass collected seven WAP revealed larger amounts of biomass present in the fall application timing of each herbicide treatment. Emergence counts conducted from early March to seven WAP revealed differences in winter and summer annual weed emergence between the four treatments. Emergence of total winter and summer annual weed species was reduced with both residual herbicide treatments when compared to glyphosate plus 2,4-D and the untreated control. The results of these studies indicate that applications of chlorimuron plus sulfentrazone plus 2,4-D at 60 days EPP offer producers the best balance of reducing spring workloads and providing optimum control of most summer and winter annual weed species.

Nomenclature: Chlorimuron; glyphosate; sulfentrazone; tribenuron; 2,4-D; annual fleabane, *Erigeron annuus* (L.) Pers. #[3] ERIAN; common chickweed, *Stellaria media* (L.) Vill. # STEME; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; common waterhemp, *Amaranthus rudis* Sauer # AMATA; corn speedwell, *Veronica arvensis* L. # VERAR; giant foxtail, *Setaria faberi* Herrm. # SETFA; henbit, *Lamium amplexicaule* L. # LAMAM; horseweed, *Conyza canadensis* (L.) Cronq. # ERICA; purslane speedwell,

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[3] Letters following this symbol are a 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.

Veronica peregrina L. # VERPG; shepherd's-purse, *Capsella bursa-pastoris* (L.) Medicus # CAPBP; soybean, *Glycine max* (L.) Merr. 'Dekalb 38-52'.

Additional index words: Fall herbicide applications, herbicide application timing, no-till, weed biomass, weed emergence, winter annuals.

Abbreviations: Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; EPP, early preplant; glyph, glyphosate; untr, untreated; WAP, weeks after planting.

INTRODUCTION

No-till soybean production offers many benefits to producers, such as reduced soil erosion, improved water retention, and reduced fuel and labor usage (Buhler 1995; Swanton et al. 1993). These are some of the primary reasons why no-till soybean production has experienced a 200 percent increase from 1990 to 2002 (CTIC 2005). With this increase in no-till production has come an increase in the severity of winter annual weed infestations. Many researchers have attributed the expansion of these infestations to widespread adoption of glyphosate-resistant soybean, and a decrease in the use of soil residual herbicides (Güeli and Smeda 2002; Hasty et al. 2002; Krausz 2003). For example, in 1996, only 25% of the total U.S. soybean acreage received glyphosate applications (USDA 1997). However, in 2006, 89% of the total U.S. soybean acreage was planted to glyphosate-resistant soybean (USDA 2006a). Herbicides with residual soil activity such as imazethapyr, pendimethalin, and imazaquin, on the other hand, were applied to 43, 27, and 15% of the total U.S. soybean acreage, respectively, in 1996 (USDA 1997). By 2005, however, their combined usage was less than six percent on all soybean acreage (USDA 2006b). Increased severity of winter annual weed infestations have also been accredited to the relatively mild winters experienced in recent years (Güeli and Smeda 2001; Webb et al. 2005).

Winter annual weed infestations can be problematic for no-till soybean producers. These weeds can interfere with planting equipment, provide alternative hosts for soybean cyst nematode (*Heterodera glycines* Ichinohe) and insect pests, and can actively compete with the developing crop (Buhler 1995; Creech et al. 2005; Dahlke et al. 2001; Kremer 2005; Venkatesh et al. 2000). Fall herbicide applications, which focus on winter annual weed removal, offer producers the benefit of reducing spring workloads, and target winter annual weeds at a more optimal growth stage (Krausz et al. 2003; Hasty et al. 2004). Many residual herbicide treatments applied in the fall have proven to be effective at controlling numerous winter annual weed species (Lee and Witt 2001; Hasty et al. 2001; Schmidt et al. 2001). However, control of summer annual weed species with these treatments has been inconsistent. Stougaard et al. (1984) obtained season-long weed control from fall applications of cyanazine plus oryzalin in areas with low weed densities. Conversely, Güeli and Smeda (2002) reported varying levels of control for giant foxtail, common lambsquarters (*Chenopodium album* L.), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.) with fall applications of residual herbicides.

Other researchers have also focused on the effects of non-residual fall herbicide applications on winter annual weed populations. Hasty et al. (2004) reported that fall applications of glyphosate plus 2,4-D provided effective control of common chickweed, henbit, and shepherd’s-purse. However, this treatment provided poor control of later-emerging winter annuals, such as annual bluegrass (*Poa annua* L.), purple deadnettle

(*Lamium purpureum* L.), and cressleaf groundsel (*Senecio glabellus* Poir.), and summer annuals such as giant ragweed (*Ambrosia trifida* L.), common ragweed, common lambsquarters, and common waterhemp. Similarly, Webb et al. (2005) reported poor control of giant ragweed 18 days after planting with fall applications of glyphosate.

Though the impacts of applying a non-residual herbicide treatment in the fall have been examined in detail, few studies have focused on determining the earliest spring application timing which provides complete removal of winter annual weed populations. Similarly, few studies have focused on determining the optimal application timing of residual herbicide treatments, which supply the most consistent winter and summer annual weed control while incorporating the cultural advantages of fall herbicide applications. Therefore, the objectives of these field experiments were to 1) evaluate the efficacy of fall versus various early spring herbicide application timings on winter annual weed populations and the emergence of summer annual weed seedlings and 2) examine differences in weed control and emergence obtained with residual and non-residual herbicide treatments applied at each one of these timings.

MATERIALS AND METHODS

Field experiments were established at three locations in Missouri in the fall of 2004 and 2005. One site was located in central Missouri at the University of Missouri Bradford Research and Extension Center, another site was located in northwest Missouri near St. Joseph, and the third site was located in northeast Missouri near Palmyra. Sites were selected based on the presence of corn residue and dense infestations of winter annual weeds. The soil type at the central Missouri location in 2004 was a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs) with 2.4% organic matter and pH of 6.3. In 2005, the central site was also a Mexico silt loam and had a pH of 6.4 with 3.0% organic matter. At the northwest site in 2004 the soil type was a Monona silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls) with 2.3% organic matter and pH of 6.0. The soil type at the 2005 northwest location was a Colo silty clay loam (fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) with 2.0% organic matter and pH of 6.7. At the 2004 northeast location the soil type was Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) with 2.0% organic matter and pH of 6.2. In 2005, the northeast site was also a Putnam silt loam and had a pH of 5.9 with 3.3% organic matter.

In all experiments, the experimental design consisted of a randomized complete block with a factorial arrangement of four treatments and four application timings, and four replications. All plots were 6 by 14 m in size. The four treatments consisted of chlorimuron plus sulfentrazone plus 2,4-D at 23 plus 115 plus 542 g ai/ha, chlorimuron plus tribenuron plus 2,4-D at 35 plus 11 plus 542 g ai/ha, glyphosate plus 2,4-D at 1120 g ae/ha plus 542 g ai/ha, and an untreated control. All three herbicide treatments were applied at four different timings: fall (mid-November), 60 days EPP (early March), 30 days EPP (early April), and seven days EPP (late April). Detailed application information is listed in Table 3.1. Additionally, specific precipitation and air temperature information is listed in Tables 3.2 and 3.3. Information on weed density and growth stage at each location and application timing is listed in Tables 3.4, 3.5, and 3.6. Treatments consisting of chlorimuron plus sulfentrazone and chlorimuron plus tribenuron received crop oil concentrate[4] at 1% v/v. Treatments containing glyphosate received ammonium sulfate at 2.9 kg/ha.

All herbicide applications were made with a CO_2 backpack sprayer set to deliver 140 L/ha at 124 kPa through XR8002[5] flat fan nozzles. Seven WAP a post application of glyphosate at 1260 g ae/ha with 2.9 kg/ha of ammonium sulfate was broadcast over each trial with a tractor-mounted sprayer.

At all locations, Dekalb '38-52' glyphosate-resistant soybean was planted in early to mid-May into a no-tillage seedbed which was planted to corn the previous year. Seed was planted in 76 cm rows at a density of 395,000 seeds/ha.

Weed control was visually assessed at soybean planting and seven WAP using a scale of 0 to 100 (0 indicating no injury and 100 representing complete plant death). Seven WAP weed biomass, consisting of both winter and summer annual weeds, was harvested from two 0.5 m^2 areas randomly selected within each plot. All weed species, including senesced winter annuals, within this area were cut off at ground level. The plant material was then dried for four days at 60 C and dry weights were recorded.

Weed seedling emergence was monitored at each location by establishing two permanent 0.5 m^2 quadrats within each plot. These quadrats were evaluated at two-week intervals beginning in early March and ending seven WAP. The number of emerged winter and summer annual weed seedlings within each quadrat were counted and recorded. Emerged seedlings were removed from each quadrat after they had been counted.

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[4] Relay brand crop oil concentrate, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

[5] Teejet Spraying Systems Co, North Avenue, Wheaton, IL 60189.

Winter and summer annual weed emergence was highly variable between years, locations, and individual experiments. Common waterhemp was the only weed species with consistent emergence across all six environments. Due to the large amount of variability in weed species, species other than common waterhemp were grouped into their respective growth habits, either winter or summer annuals. Data was then summarized across all counting dates to give an accumulated emergence of common waterhemp and winter and summer annual weeds from early March to seven WAP. Treatment by application timing interactions for the emergence data were not significant, therefore, treatment means were averaged across timings to display significant differences in treatments.

Data Analysis. All data were analyzed using the Proc Mixed procedure in SAS (2005). As suggested by Carmer et al. (1989), each year-location combination was considered an environment sampled at random. Fixed effects in the model were herbicide treatment and application timing. Random effects included environment, replications (nested within environments), and all interactions with environment and replications. Considering environments at random enables inferences about the treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003; Hasty et al. 2004). Individual treatment differences were detected by using Fisher's protected LSD at $P < 0.05$. Weed control data were transformed using arcsine of the square root. Transformation did not alter data interpretation, therefore, nontransformed weed control means are presented. Square root transformations did improve the model for both weed biomass and weed emergence data. Analyses for these data were performed on the transformed means. Means were then back transformed for data presentation.

RESULTS AND DISCUSSION

Winter Annual Weed Control at Planting. Control of all seven winter annual weed species was highly influenced by application timing (Table 3.7). Both residual treatments applied 7 days EPP provided significantly lower control of all winter annual weed species, except common chickweed and corn speedwell, than the other three previous timings. Common chickweed control was greater than 80% from all treatments except chlorimuron plus sulfentrazone plus 2,4-D applied in the fall, 60 days EPP, and 30 days EPP. The 7 day EPP application timing was the only chlorimuron plus sulfentrazone plus 2,4-D treatment to provide adequate control of common chickweed. Control at this application timing may have been increased due to the onset of natural plant death at the time of soybean planting.

Purslane speedwell control was greatest from fall, 60 day EPP, and 30 day EPP residual treatments. However, when residual treatments were applied to purslane speedwell in the flowering stage at 7 days EPP, control was less than 76% at planting. Control from glyphosate plus 2,4-D was dependent on purslane speedwell germination patterns. Glyphosate plus 2,4-D applied in the fall and 60 days EPP provided the poorest control of purslane speedwell. Control increased to 94% at the 30 day EPP timing, indicating that significant purslane speedwell emergence occurred in the early spring after the 60 day EPP application. Baskin and Baskin (1983) reported similar plasticity in purslane speedwell germination.

Annual fleabane control was similar to that of purslane speedwell. Control from the two residual treatments was 99% at all timings except at 7 days EPP. Glyphosate plus

2,4-D applied 30 days EPP was the only non-residual treatment to provide adequate control of annual fleabane. Early spring germination caused the decrease in control from glyphosate plus 2,4-D applied in the fall and 60 days EPP, while the presence of annual fleabane in the flowering stage likely caused the decrease in control at the 7 day EPP timing.

Control of corn speedwell was 98% from both fall-applied residual treatments, however, the only spring treatment to provide greater than 80% control of corn speedwell was glyphosate plus 2,4-D applied 30 days EPP. Shepherd's-purse was another winter annual weed displaying some spring germination. Glyphosate plus 2,4-D applied in the fall and 60 days EPP provided less control of shepherd's-purse than the two later glyphosate plus 2,4-D treatments. This is contradictory to the findings of Hasty et al. (2004), who reported excellent control of shepherd's-purse from fall applications of glyphosate plus 2,4-D. Shepherd's-purse control from all residual treatments was 99%, except those applied at 7 days EPP.

Control of horseweed was also highly dependent on application timing. All residual treatments provided greater than 96% control of horseweed except those applied at 7 days EPP. Spring germination of horseweed led to a decrease in control from glyphosate plus 2,4-D applied in the fall and 60 days EPP.

Henbit control was excellent (greater than 94%) from all fall, 60 day EPP, and 30 day EPP treatments. However, control at the 7 day EPP application timing was reduced with all treatments. Henbit at this timing was in the flowering stage, which was likely a factor in the reduced control observed at this timing.

Summer and Winter Annual Weed Control Seven WAP. At seven WAP, control of horseweed and annual fleabane was similar within treatments and application timings (Table 3.8). Control of both horseweed and annual fleabane was greater than 88% from all treatments except glyphosate plus 2,4-D applied in the fall and 60 days EPP. Early spring germination of both species after the 60 day EPP application timing contributed to this reduced level of control.

Control of the other three summer annual weed species seven WAP was more variable. All fall treatments provided relatively poor control of common waterhemp. Chlorimuron plus sulfentrazone plus 2,4-D applied 60 days EPP, 30 days EPP, and 7 days EPP were the only treatments that provided greater than 84% control of common waterhemp. Chlorimuron plus tribenuron plus 2,4-D and glyphosate plus 2,4-D provided similar control of common waterhemp within each application timing. Common ragweed control was greater than 89% with all fall and early spring residual treatments, and with glyphosate plus 2,4-D applied 7 days EPP. All other glyphosate treatments provided less than 44% control of common ragweed. Control of giant foxtail was highly variable with ratings ranging from 0 to 95%. Glyphosate plus 2,4-D treatments applied prior to 7 days EPP provided less than 23% control of giant foxtail. The 7 day EPP treatment of glyphosate plus 2,4-D was the only non-residual treatment to provide at least 80% control. Both fall residual treatments provided a lower level of giant foxtail control. However, all spring residual treatments provided greater than 83% giant foxtail control, except chlorimuron plus sulfentrazone plus 2,4-D applied 60 days EPP.

Weed Biomass. When compared within herbicide treatments, the fall application timing had significantly more weed biomass than any of the other three timings (Figure 3.1).

Applications of glyphosate plus 2,4-D in the fall resulted in similar amounts of weed biomass as the untreated control. This was due to its non-residual nature, which allowed for the establishment of spring germinating weed species. When compared to the two residual treatments, glyphosate plus 2,4-D resulted in significantly higher amounts of weed biomass at each application timing, except at 7 days EPP. Both residual treatments produced similar amounts of biomass at all application timings except 60 days EPP. Applications of chlorimuron plus sulfentrazone plus 2,4-D at this application timing resulted in significantly less weed biomass than chlorimuron plus tribenuron plus 2,4-D within the same timing.

Weed Emergence. The emergence of total winter annual weeds ranged from one to eight plants per 0.5 m^2 (Figure 3.2). Emergence of winter annual weeds was largest in the untreated and glyphosate plus 2,4-D treatments. Winter annual weed emergence was minimal in plots that received residual herbicide treatments. There was also a significant effect of application timing on winter annual weed emergence (data not shown). Fall applications resulted in the largest amount of emergence with nine plants per 0.5 m^2. Emergence of winter annuals at the 60 day EPP timing was significantly lower than at the fall application, but significantly higher than the other two spring applications. Winter annual weed emergence was lowest at the 30 and 7 day EPP application timings with approximately two emerged plants per 0.5 m^2 in each respective timing.

The degree of common waterhemp emergence was also significantly impacted by herbicide treatment (Figure 3.2). The chlorimuron plus sulfentrazone plus 2,4-D treatment resulted in the lowest amount of common waterhemp emergence when compared to the other three treatments. There was no significant difference in common waterhemp emergence between the chlorimuron plus tribenuron plus 2,4-D, glyphosate plus 2,4-D, and untreated control treatments. Emergence in these treatments ranged from 16 to 18 plants per 0.5 m^2, and was significantly higher than that obtained in the chlorimuron plus sulfentrazone plus 2,4-D treatment. Treatment differences in common waterhemp emergence were similar to differences in common waterhemp control. In both measurements, chlorimuron plus sulfentrazone plus 2,4-D exhibited a higher level efficacy on common waterhemp than the other two herbicide treatments.

Reduction in summer annual weed emergence was dependent on residual activity. Applications of the two residual treatments, chlorimuron plus sulfentrazone plus 2,4-D and chlorimuron plus tribenuron plus 2,4-D, led to lower overall emergence of summer annuals when compared to the non-residual, glyphosate plus 2,4-D or untreated control treatments. Overall, summer annual weed emergence corresponded with summer annual weed control ratings, which were generally higher for the two residuals treatments across all four timings.

Our findings suggest that fall applications of residual herbicides can provide a clean seedbed for planting. However, the control of summer annual weed species that emerge later in the spring with these treatments is inconsistent. Seven day EPP herbicide applications offer more favorable summer annual weed control seven WAP, yet their control of winter annual weed species at planting is inadequate. Thirty and 60 day EPP applications of residual herbicide treatments offer the best balance of winter annual weed control at planting and summer annual weed control seven WAP. This is similar to the results reported by Hasty et al. (2004) with 30 day EPP applications of residual herbicide treatments. Our data suggests that applications of chlorimuron plus sulfentrazone plus

2,4-D at 60 days EPP might offer producers the best balance of reducing spring workloads and providing optimum control of most summer and winter annual weed species.

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Table 3.1. Herbicide application and planting information for the central, northwest, and northeast Missouri field experiments conducted in 2004-2005 and 2005-2006.

	Central		Northwest		Northeast	
	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006
Application dates						
Fall	November 12	November 4	November 22	November 10	November 23	November 21
60 EPP	March 3	February 28	March 14	March 2	March 4	March 7
30 EPP	April 6	April 4	April 13	March 28	April 1	April 4
7 EPP	May 3	April 25	May 9	April 27	April 25	May 2
Soil temperature[a]						
Fall	14.4	11.1	8.9	9.4	10.2	6.1
60 EPP	8.3	10.6	5.6	4.4	5.9	3.9
30 EPP	11.7	16.1	11.7	4.4	13.3	10.6
7 EPP	11.7	12.2	17.8	8.9	9.4	11.1
Planting dates	May 17	May 8	May 23	May 15	May 3	May 10

[a] Soil temperature in degrees Celsius taken at a 5 cm depth.

Table 3.2. Precipitation from March through July at the central, northwest, and northeast Missouri locations in 2005 and 2006.

	Central		Northwest		Northeast	
	2005	2006	2005	2006	2005	2006
	----------mm----------					
Month						
March	24	92	19	54	25	89
April	92	52	80	115	55	52
May	78	81	115	42	38	33
June	91	96	165	72	57	110
July	11	77	30	98	22	58
Total[a]	296	398	409	381	197	342

[a] Total rainfall from March 1 to July 31.

Table 3.3. Maximum and minimum air temperature from March through July at the central, northwest, and northeast Missouri locations in 2005 and 2006.

	Central				Northwest				Northeast			
	2005		2006		2005		2006		2005		2006	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
	----------------------------------C----------------------------------											
Month												
March	26	-7	25	-5	23	-9	24	-6	25	-7	26	-9
April	27	-1	31	0	26	-1	32	0	28	-1	31	-2
May	30	1	32	6	31	0	33	6	30	-1	34	4
June	34	14	32	13	34	14	34	13	36	11	33	12
July	39	14	38	14	36	13	37	15	41	12	38	1

Table 3.4. Weed species, density, and stage at application for the central Missouri location in 2004-2005 and 2005-2006.[a,b]

	Central											
	Fall			60EPP			30EPP			7EPP		
Species	Density[c]	Stage[d]	Height[e]	Density	Stage	Height	Density	Stage	Height	Density	Stage	Height
2004-2005												
LAMAM	55	vegetative	6	39	vegetative	6	18	flowering	8	8	senescing	15
STEME	27	vegetative	4	38	vegetative	5	20	flowering	8	15	flowering	25
CARPA	6	rosette	8	5	rosette	8	3	flowering	8	5	senescing	15
THLAR	1	rosette	10	1	rosette	10	1	flowering	10	1	senescing	46
ERIAN	1	rosette	8	1	rosette	8	1	rosette	18	3	bolting	20
VERPG	1	vegetative	2	1	vegetative	2	1	vegetative	3	3	flowering	13
VERAR	1	vegetative	2	1	vegetative	2	2	vegetative	3	4	flowering	10
2005-2006												
LAMAM	17	cotyledon	1	18	vegetative	8	20	flowering	8	6	senescing	10
STEME	46	vegetative	8	25	vegetative	8	25	flowering	8	15	flowering	10
CARPA	17	rosette	10	8	rosette	10	6	bolting	5	1	senescing	13
ERIAN	1	rosette	10	1	rosette	15	1	rosette	15	1	bolting	18
VERPG	1	cotyledon	1	2	vegetative	2	2	vegetative	3	8	flowering	15

[a] LAMAM, henbit; STEME, common chickweed; CARPA, smallflowered bittercress; THLAR, field pennycress; ERIAN, annual fleabane; VERPG, purslane speedwell; VERAR, corn speedwell.
[b] EPP, early preplant.

[c] Density denotes the average number of plants per 0.5 m^2
[d] Predominant growth stage of the plant species at the time of application.
[e] Average height of the plant species in cm. For plants in the rosette stage, this measurement indicates diameter of the plant.

Table 3.5. Weed species, density, and stage at application for the northwest Missouri location in 2004-2005 and 2005-2006.[a,b]

	Northwest											
	Fall			60EPP			30EPP			7EPP		
Species	Density[c]	Stage[d]	Height[e]	Density	Stage	Height	Density	Stage	Height	Density	Stage	Height
2004-2005												
LAMAM	71	vegetative	4	60	vegetative	5	45	flowering	15	37	senescing	20
DESPI	1	rosette	4	1	rosette	5	1	bolting	18	1	flowering	50
2005-2006												
LAMAM	61	vegetative	5	29	vegetative	8	19	vegetative	8	6	flowering	18
STEME	20	vegetative	8	8	vegetative	8	14	vegetative	9	4	flowering	18
DESPI	1	rosette	4	1	rosette	4	1	bolting	5	1	flowering	36

[a] LAMAM, henbit; DESPI, pinnate tansymustard; STEME, common chickweed.
[b] EPP, early preplant.
[c] Density denotes the average number of plants per 0.5 m^2
[d] Predominant growth stage of the plant species at the time of application.
[e] Average height of the plant species in cm. For plants in the rosette stage, this measurement indicates diameter of the plant.

Table 3.6. Weed species, density, and stage at application for the northeast Missouri location in 2004-2005 and 2005-2006.[a,b,c]

	Northeast											
	Fall			60 days EPP			30 days EPP			7 days EPP		
Species	Density[d]	Stage[e]	Height[f]	Density	Stage	Height	Density	Stage	Height	Density	Stage	Height
2004-2005												
LAMAM	13	vegetative	4	3	vegetative	5	2	flowering	5	4	senescing	11
STEME	38	vegetative	2	25	vegetative	5	14	vegetative	5	18	flowering	10
THLAR	0	---	--	0	---	--	6	cotyledon	1	13	flowering	11
VERPG	0	---	--	0	---	--	2	cotyledon	1	22	flowering	10
VERAR	6	vegetative	2	3	vegetative	2	1	vegetative	3	3	flowering	5
RANAR	9	rosette	5	4	rosette	5	1	bolting	5	6	flowering	23
CAPBP	0	---	--	0	---	--	0	---	--	7	rosette	5
2005-2006												
STEME	46	vegetative	5	18	vegetative	9	21	vegetative	1	9	flowering	18
THLAR	1	rosette	5	1	rosette	5	1	bolting	8	1	flowering	50
ERIAN	0	---	--	0	---	--	1	rosette	10	1	bolting	18
VERPG	0	---	--	1	cotyledon	1	1	vegetative	4	6	flowering	13
VERAR	7	vegetative	2	1	vegetative	2	1	vegetative	3	1	flowering	8
CAPBP	0	---	--	0	---	--	1	rosette	7	1	flowering	50

[a] LAMAM, henbit; STEME, common chickweed; THLAR, field pennycress; VERPG, purslane speedwell; VERAR, corn speedwell; RANAR, corn buttercup; CAPBP, shepherd's-purse; ERIAN, annual fleabane.

[b] EPP, early preplant.
[c] -- indicates species that were not present at the time of application.
[d] Density denotes the average number of plants per 0.5 m^2
[e] Predominant growth stage of the plant species at the time of application.
[f] Average height of the plant species in cm. For plants in the rosette stage, this measurement indicates diameter of the plant.

Table 3.7. Winter annual weed control at the time of soybean planting from fall, 60, 30, and 7 day EPP herbicide applications at the central, northwest, and northeast Missouri locations in 2005 and 2006.[a]

			Weed species[b]						
Timing	Treatment[c]	Rate[d]	STEME	VERPG	ERIAN	VERAR	CAPBP	ERICA	LAMAM
		g ai/ha	% control						
Fall	Chlorimuron + sulfentrazone	23 + 115	69	99	99	98	99	98	99
	Chlorimuron + tribenuron	35 + 11	98	99	99	98	99	97	99
	Glyphosate	1120	91	33	66	71	59	50	94
60EPP	Chlorimuron + sulfentrazone	23 + 115	47	99	99	70	99	96	94
	Chlorimuron + tribenuron	35 + 11	99	99	99	64	99	96	96
	Glyphosate	1120	82	39	68	75	67	56	97
30EPP	Chlorimuron + sulfentrazone	23 + 115	40	99	99	62	99	99	96
	Chlorimuron + tribenuron	35 + 11	99	99	99	62	99	99	96
	Glyphosate	1120	98	94	96	94	96	99	97
7EPP	Chlorimuron + sulfentrazone	23 + 115	92	76	44	62	58	33	75
	Chlorimuron + tribenuron	35 + 11	96	66	37	60	46	33	62
	Glyphosate	1120	98	88	61	62	81	49	69
LSD (0.05)[e]			7	8	12	11	12	16	6
Environments[f]			5	5	3	3	2	2	2

[a] EPP, early preplant.

[b] STEME, common chickweed; VERPG, purslane speedwell; ERIAN, annual fleabane; VERAR, corn speedwell; CAPBP, shepherd's-purse; ERICA, horseweed; LAMAM, henbit.
[c] All treatments included 2,4-D at 542 g ai/ha. All treatments containing chlorimuron plus sulfentrazone and chlorimuron plus tribenuron included crop oil concentrate at 1% v/v.
[d] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.
[e] LSD applies to all comparisons within a species.
[f] Number of environments in which a species was present.

Table 3.8. Summer and winter annual weed control at seven weeks after planting from fall, 60, 30, and 7 day EPP herbicide applications at the central, northwest, and northeast Missouri locations in 2005 and 2006.[a]

			Weed species[b]				
Timing	Treatment[c]	Rate[d]	ERICA	ERIAN	AMATA	AMBEL	SETFA
		g ai/ha	---% control---				
Fall	Chlorimuron + sulfentrazone	23 + 115	95	99	61	89	58
	Chlorimuron + tribenuron	35 + 11	96	99	28	89	71
	Glyphosate	1120	76	74	20	39	0
60EPP	Chlorimuron + sulfentrazone	23 + 115	90	97	84	93	71
	Chlorimuron + tribenuron	35 + 11	93	98	48	98	88
	Glyphosate	1120	74	73	42	35	6
30EPP	Chlorimuron + sulfentrazone	23 + 115	91	99	85	95	83
	Chlorimuron + tribenuron	35 + 11	95	99	61	98	90
	Glyphosate	1120	88	94	55	44	23
7EPP	Chlorimuron + sulfentrazone	23 + 115	93	98	91	94	95
	Chlorimuron +tribenuron	35 + 11	97	99	75	99	89
	Glyphosate	1120	98	96	70	91	80
LSD (0.05)[e]			6	10	8	16	14
Environments[f]			6	4	4	2	2

[a] EPP, early preplant.

[b] ERICA, horseweed; ERIAN, annual fleabane; AMATA, common waterhemp; AMBEL, common ragweed; SETFA, giant foxtail.
[c] All treatments included 2,4-D at 542 g ai/ha. All treatments containing chlorimuron plus sulfentrazone and chlorimuron plus tribenuron included crop oil concentrate at 1% v/v.
[d] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.
[e] LSD applies to all comparisons within a species.
[f] Number of environments in which a species was present.

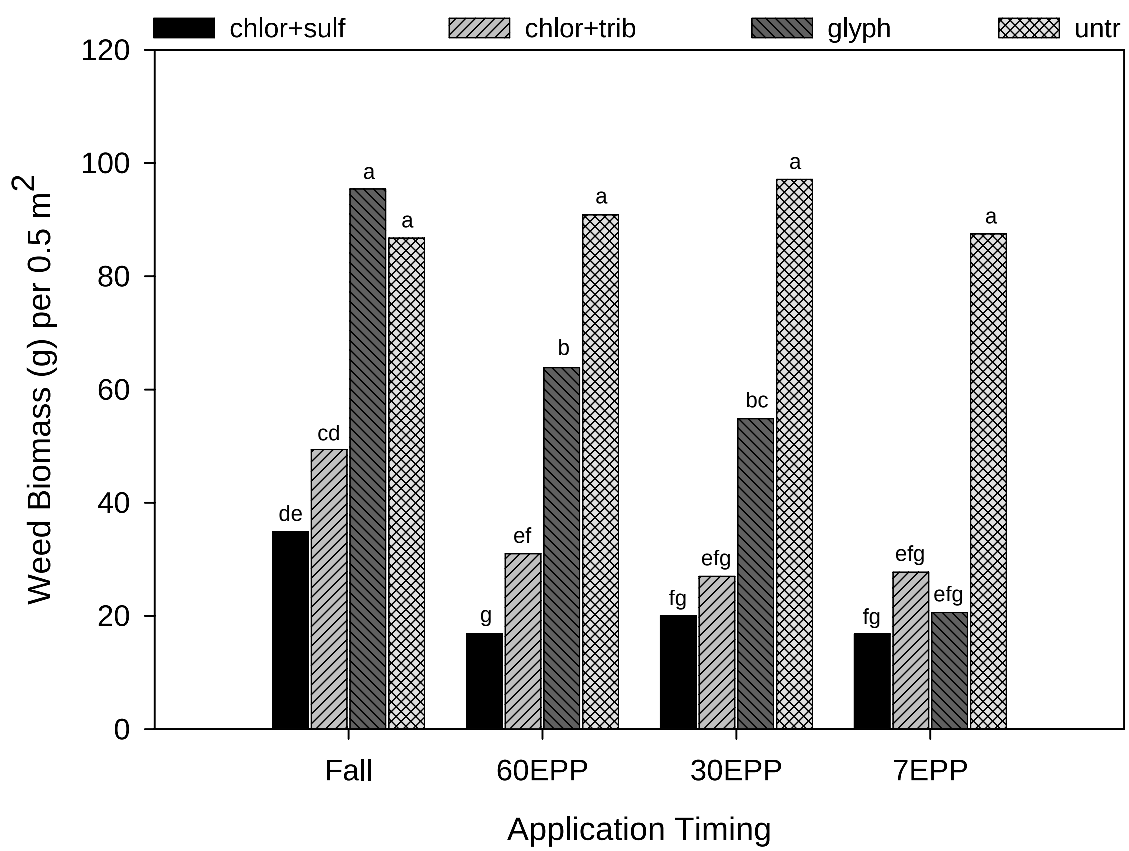

Figure 3.1. Impact of fall and early spring herbicide applications on total weed biomass seven weeks after planting. Vertical bars indicate dry weight measurements of weed biomass per 0.5 m^2. Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; glyph, glyphosate; untr, untreated. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment means with different letters indicate significant differences ($P < 0.05$) in total weed biomass and should be used for all comparisons across timings and treatments.

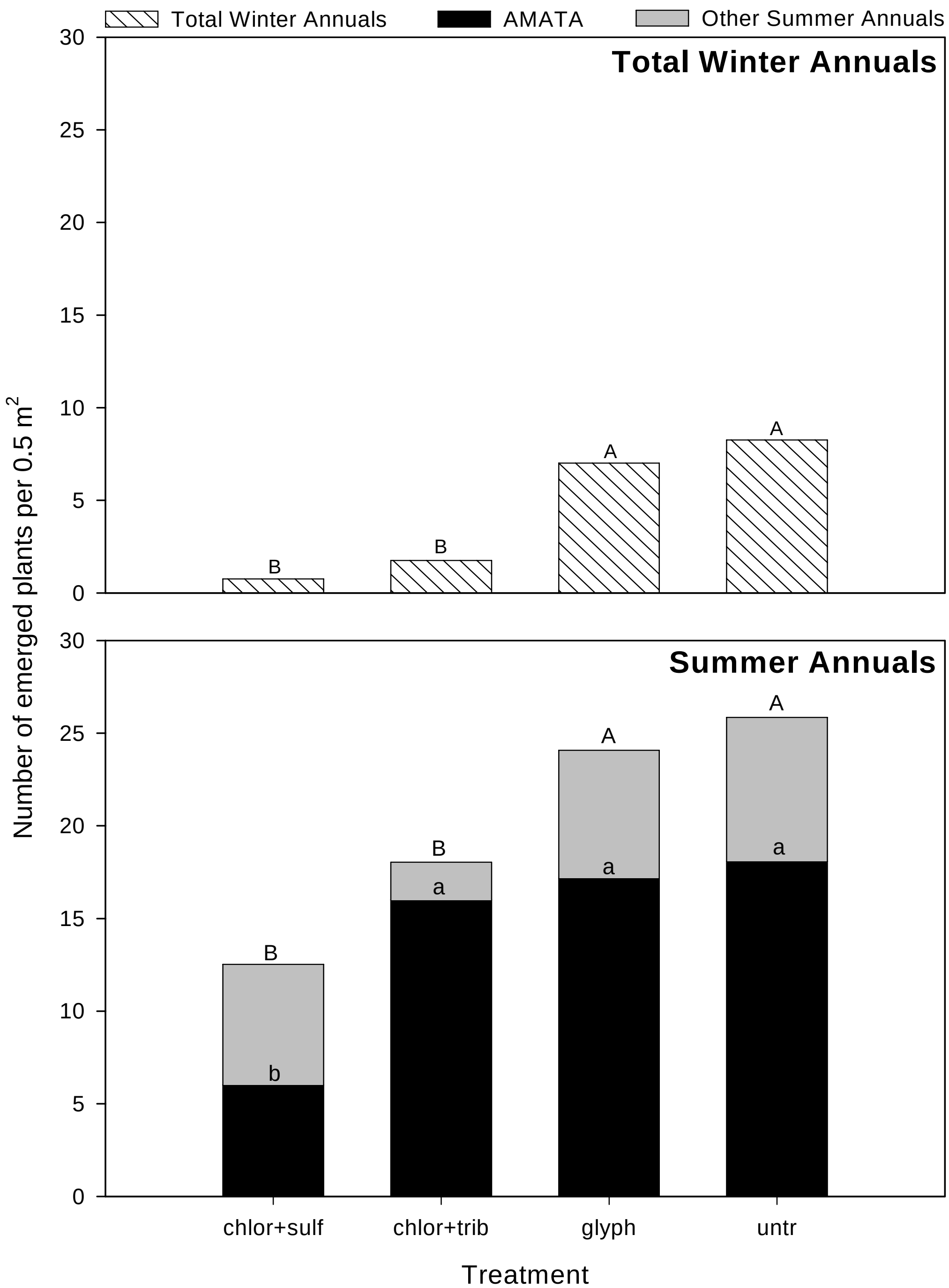

Figure 3.2. Influence of fall and early spring herbicide applications on total emergence of winter annual weed species (Total Winter Annuals), common waterhemp (AMATA), and summer annual weed species (AMATA plus Other Summer Annuals). Chlor+sulf, chlorimuron plus sulfentrazone; chlor+trib, chlorimuron plus tribenuron; glyph, glyphosate; untr, untreated. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment by timing interactions were not significant, therefore, treatment means were averaged across timings. Treatment means with different upper-case letters indicate significant differences ($P < 0.05$) in total winter and summer annual weed emergence. Treatment means with different lower-case letters indicate significant differences ($P < 0.05$) in total common waterhemp emergence.

Chapter IV

Impact of Fall and Early Spring Herbicide Applications on Insect Injury and Soil Conditions in No-Till Corn[1]

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Abstract. Fall herbicide applications have increased in popularity in recent years, yet little is known of how these applications affect various agronomic factors. Field studies were established at two Missouri locations in 2004 and 2005 to evaluate the effects of fall and early spring herbicide applications on soil temperature, soil moisture content, and insect injury in no-till corn production systems. Both experiments received applications of simazine plus 2,4-D, rimsulfuron plus thifensulfuron plus 2,4-D, and glyphosate plus 2,4-D in the fall, 45 days prior to planting (45 days EPP), 30 days prior to planting (30 days EPP), and seven days prior to planting (7 days EPP). During a period from April 1 to April 14, simazine plus 2,4-D applied 45 days EPP did result in higher soil temperatures at a 5 cm depth compared to the untreated control. However, there were few differences in soil temperature present from April 15 to May 1. Soil moisture readings taken during this same time period corresponded with soil temperature readings. Measurements of soil moisture taken at one and three weeks after planting (WAP)

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[1] Received for publication___and in revised form___.

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revealed significantly lower soil moisture readings in the untreated compared to herbicide treated plots. This lower soil moisture content allowed untreated plots to warm up more rapidly and thereby eliminated any negative impacts that dense stands of winter annual weeds may have had on soil temperature. Evaluations of corn flea beetle (*Chaetocnema pulicaria* Melsheimer) and lepidopteran injury taken at the V2, V4, and V6 corn leaf stages revealed significant differences in injury as a result of these treatments. When dense stands of winter and summer annual weeds were left uncontrolled, corn flea beetle injury was significantly lower than in plots treated with a herbicide. However, when a post herbicide application was made to remove all weed species prior to the V6 sampling date, differences in corn flea beetle injury between the untreated and herbicide treated plots were eliminated. Additionally, removal of all weed species led to higher lepidopteran injury in the untreated. Fall and early spring herbicide applications have limited value in accelerating the soil warming and drying process in the spring. However, these applications can decrease lepidopteran insect feeding well after planting.

Nomenclature: Glyphosate; rimsulfuron; simazine; thifensulfuron; 2,4-D; corn, *Zea mays* L. 'Pioneer 34B23'.

Additional index words: *Chaetocnema pulicaria*, corn flea beetle, fall herbicide applications, herbicide application timing, Lepidoptera, no-till, soil moisture, soil temperature, weed-insect interactions, winter annuals.

Abbreviations: EPP, early preplant; rim+thifen, rimsulfuron plus thifensulfuron; WAP, weeks after planting.

INTRODUCTION

Glyphosate usage on corn acreage here in the U.S. has steadily increased in recent years. In 2005, glyphosate was applied to 33% of all U.S. corn acreage (USDA 2006). That is a 29% increase from 1996 (USDA 1997). This increase in glyphosate-resistant corn usage has brought with it a shift in corn tillage practices. Approximately 14 million acres were planted to no-till corn in the U.S. in 2000. In 2004, however, this area had increased to almost 16 million acres (CTIC 2005). The increased usage of glyphosate-resistant crops coupled with the increase in no-till corn production has provided a favorable environment for winter annual weed establishment (Buhler 2002; Güeli and Smeda 2001; Webb et al. 2005). Winter annual weeds left uncontrolled until spring planting can interfere with planting equipment and can become difficult to control with herbicides (Buhler 1995; Kapusta 1979; Wilson et al. 1985). Applications of residual herbicides in the fall can provide acceptable control of many winter annual weeds, and may eliminate the need for a burndown application prior to planting (Hasty et al. 2004; Krausz et al. 2003). However, fall herbicide applications may offer benefits other than just winter annual weed control.

Several researchers have hypothesized that removing winter annual weeds in the fall will accelerate the soil warming and drying process in the spring (Dahlke et al. 2001; Kremer 2005). Lee and Witt (2001) reported that plots treated with fall applications of atrazine or simazine to control henbit (*Lamium amplexicaule* L.) had warmer soil surface temperatures than untreated plots. However, Krausz et al. (2003) observed no significant differences in soil temperatures at a 5 cm depth between plots treated with a herbicide in the fall and plots left untreated. Though the direct impacts of fall herbicide applications on soil moisture have been relatively undocumented, there is a large amount of information available on the effects of soil moisture on weed emergence. Blackshaw et al. (2002) reported that henbit emergence was greatest at relatively high soil water levels (-0.03 MPa). Similarly, Blackshaw (1991) noted that germination of downy brome (*Bromus tectorum* L.) decreased when soil moisture potential fell below -1.03 Mpa. In a large scale study testing 17 weed and five crop species, Hoveland and Buchanan (1973) concluded that most weed seed required more moisture for germination than crop seed. These results indicate that if fall herbicide applications enabled soils to dry faster in the spring, they would not only facilitate earlier corn planting, but also provide an environment conducive to crop emergence and discouraging to overall weed emergence.

Removal of winter annual weeds through fall herbicide applications may also influence insect pest populations present in no-till corn production fields. The black cutworm [*Agrotis ipsilon* (Hufnagel)] is one insect pest that could be greatly impacted by the use of fall-applied herbicides. This insect is incapable of overwintering in northern Corn Belt climates. Therefore, adult moths must migrate into this area from southern states in early spring (Showers et al. 1989a; Showers et al. 1989b; Story and Keaster 1982). This migration takes place prior to corn planting, so the moths must utilize alternative weed hosts as sites for food, shelter, and oviposition. Several winter annual weed species, such as common chickweed [*Stellaria media* (L.) Vill.], shepherd's-purse [*Capsella bursa-pastoris* (L.) Medicus], mouseear chickweed (*Cerastium vulgatum* L.), yellow rocket (*Barbarea vulgaris* R. Br.), Virginia pepperweed (*Lepidium virginicum* L.), and purslane speedwell (*Veronica peregrine* L.) are utilized by the moths as sites for oviposition (Busching and Turpin 1976; Johnson et al. 1984; Sherrod et al. 1979). When these alternative hosts are removed from a developing corn field, the black cutworm larvae then begin feeding on the seedling corn. Therefore, removal of winter annual weeds in the fall could reduce damage caused by black cutworm larvae in the spring.

Pavuk and Stinner (1991) determined that stalk borer (*Papaipema nebris* Guenée) populations could also be influenced by the presence of winter annual weeds. They reported that stalk borer damage was higher in plots containing the winter annual rough fleabane (*Erigeron strigosus* Muhl. ex Willd.) than plots where it was absent. Similarly, Levine (1993) noted that the absence of winter annual weeds such as common chickweed and yellow rocket (*Barbarea vulgaris* R. Br.) in the spring led to a decrease in stalk borer larval infestations. Removal of winter annual weeds with fall-applied herbicides may also lead to a decrease in the incidence and severity of stalk borer populations in no-till corn production fields.

Fall herbicide applications offer many benefits to no-till corn producers. They enable producers to reduce spring workloads, and may eliminate the need for a spring burndown application prior to planting (Hasty et al. 2004; Krausz et al. 2003). These are the primary reasons why fall herbicide applications have increased in popularity in recent years. However, there is little information available on the effect of fall and spring herbicide applications on soil temperature and soil moisture. There is also limited information available on the effects of winter annual weed removal through fall herbicide applications on insect injury in no-till corn. Therefore, the objectives of these experiments were to 1) determine the impact of fall and early spring herbicide applications on soil temperature and moisture and 2) to evaluate the effects of fall and early spring herbicide applications on insect injury in no-till corn.

MATERIALS AND METHODS

Field experiments were established at two Missouri locations in the fall of 2004 and 2005. One site was located in central Missouri at the University of Missouri Bradford Research and Extension Center, while the other was located in northwest Missouri near St. Joseph. Sites were selected based on the presence of soybean residue and dense infestations of winter annual weeds. The soil type at the central Missouri location in 2004 and 2005 was a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs). This site had a pH of 5.8 with 1.8% organic matter in 2004. In 2005, this location had a pH of 6.3 with 2.1% organic matter. At St. Joseph, the soil type was a Colo silty clay loam (fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) in both 2004 and 2005. This site had a pH of 6.2 with 2.9% organic matter in 2004. In 2005, this location had a pH of 6.1 with 2.4% organic matter.

In all experiments, the experimental design consisted of a randomized complete block with a factorial arrangement of four treatments and four application timings, and four replications. All plots were 6 by 14 m in size. The four treatments consisted of simazine plus 2,4-D at 1120 plus 542 g ai/ha, rimsulfuron plus thifensulfuron plus 2,4-D at 13 plus 7 plus 542 g ai/ha, glyphosate plus 2,4-D at 1120 g ae/ha plus 542 g ai/ha, and an untreated control. All three herbicide treatments were applied at four different timings: fall (mid-November), 45 days prior to planting (early March), 30 days prior to planting (mid-March), and seven days prior to planting (early April). Detailed application information is listed in Table 4.1. Additionally, specific precipitation and air temperature information is listed in Table 4.2. Treatments consisting of simazine and rimsulfuron plus thifensulfuron received crop oil concentrate[3] at 1% v/v. Treatments containing glyphosate received ammonium sulfate at 2.9 kg/ha.

All herbicide applications were made with a CO_2 backpack sprayer set to deliver 140 L/ha at 124 kPa through XR8002[4] flat fan nozzles. Five WAP a post application of atrazine plus mesotrione plus nicosulfuron plus rimsulfuron at 2,240 plus 105 plus 20 plus 10 g ai/ha was broadcast over each trial with a tractor-mounted sprayer. This treatment also contained crop oil concentrate at 1% v/v and 28% urea ammonium nitrate fertilizer[5] at 3.5% v/v.

At all locations, Pioneer '34B23' was planted in mid to late April into a no-tillage seedbed which was planted to soybean the previous year. This corn variety was used because it contained no seed treatments, which might influence injury levels caused by early season insect pests. Seed was planted in 76 cm rows at a density of 71,000 seeds/ha.

Soil Moisture. Soil moisture measurements were taken at bi-weekly intervals beginning in early March and continuing until three WAP. A Field Scout TDR 300 Soil Moisture Probe[6] was used to measure and record the percent volumetric water content within the soil. Four random measurements were taken in each plot at a depth of 12 cm resulting in a total of 16 measurements of soil moisture per treatment. On the day of sampling, soil moisture measurements were taken between the hours of 10:00 a.m. and 3:00 p.m.

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[3] Relay brand crop oil concentrate, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

[4] Teejet Spraying Systems Co, North Avenue, Wheaton, IL 60189.

[5] Urea ammonium nitrate fertilizer containing 28% nitrogen obtained in bulk, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

[6] Spectrum Technologies, Inc., 12360 South Industrial Drive, Plainfield, IL 60585.

Soil Temperature. Evaluations of soil temperature were not made in 2005, but were conducted at both locations in 2006. Soil temperature measurements were recorded with Hobo Pro Temp Data Loggers[7] inserted to a depth of 5 cm. These thermometers logged the soil temperature each day at 12:00 p.m. Thermometers were only placed within the 45 days EPP application timing of simazine plus 2,4-D and the untreated control treatments. Thermometers were placed within these plots in order to evaluate differences in soil temperature between the most weed-free treatment and the untreated control plots that remained covered with winter annual weeds throughout the duration of the experiment. One thermometer was randomly placed within each plot of these two treatments for a total of four thermometers per treatment at each location. Measurements of soil temperature began in early March and continued until late May.

Insect Injury. Due to low insect densities in both years, damage caused by the stalk borer, armyworm (*Pseudaletia unipuncta* Haworth), sod webworm (*Herpetogramma phaeopteralis* Guenée), and black cutworm were grouped into one category called lepidopteran injury. Evaluations of insect damage were conducted at the V2, V4, and V6 corn leaf stages at the central location in 2005 and 2006. The growth stage was determined by taking the average corn leaf stage within the herbicide treatments. Due to intense weed competition, the corn plants within the untreated plots were in a more inferior growth stage than those in the herbicide treated plots within each sampling date. Two random samples, each consisting of one meter row lengths, were taken from each plot in which the number of corn plants damaged by corn flea beetle (*Chaetocnema pulicaria* Melsheimer) and/or lepidopteran feeding were counted and recorded. The

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[7] Onset Computer Corporation, 470 MacArthur Boulevard, Bourne, MA 02532.

number of corn plants damaged by each respective type of feeding was then divided by the total number of corn plants per meter of row to generate a percentage of plants displaying either corn flea beetle or lepidopteran injury for each sample.

Data analysis. All data were analyzed using the Proc Mixed procedure in SAS (2005). As suggested by Carmer et al. (1989), each year-location combination was considered an environment sampled at random. For soil moisture data, fixed effects in the model were herbicide treatment and application timing. Random effects included environment, replications (nested within environments), and all interactions with environment and replications. Soil temperature data were analyzed using replication and replication by location interactions as random effects, while treatment was used as a fixed effect. For insect injury data, replication and replication by year interactions were used as random effects, and herbicide treatment and application timing were used as fixed effects. Considering environments at random enables inferences about the treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003; Hasty et al. 2004). Individual treatment differences were detected by using Fisher's protected LSD at $P < 0.05$. Nontransformed means are presented because transformations did not alter the data interpretation.

RESULTS AND DISCUSSION

Soil Moisture. There were no significant differences in soil moisture between any of the treatments or application timings in the March and early April sampling dates (data not shown). However, significant treatment by application timing interactions were present at the one WAP and three WAP dates (Table 4.3). At one WAP, volumetric soil moisture ranged from 37.8% to 54.0% within all treatments and application timings. Volumetric soil moisture content on this date was significantly lower in the untreated control plots. When compared within timings, the untreated ranged from 5% to 12% lower in soil moisture content than the herbicide treated plots. The two residual herbicide treatments applied at 7 days EPP also exhibited lower soil moisture contents than similar treatments applied at the previous three application timings. The 7 day EPP treatments had only been applied approximately 14 days prior to the one WAP sampling date, and, therefore, complete removal of winter annual weeds had not yet taken place. When comparing non-residual treatments, glyphosate plus 2,4-D applied at 7 days EPP had a lower soil moisture content than the other two previous spring applications, however, soil moisture at this timing was not lower than the fall application of glyphosate plus 2,4-D. Glyphosate plus 2,4-D applied in the fall provided poor control of field pennycress, which displayed significant levels of late fall or early spring germination (data not shown). The presence of dense populations of field pennycress translated into reduced soil moisture content for fall applications of glyphosate plus 2,4-D.

Soil moisture at the three WAP sampling date was less variable. Volumetric soil moisture content ranged from only 40.2% to 50.8%. On this date, the lowest volumetric soil moisture content was obtained from the fall-applied glyphosate plus 2,4-D treatment. Soil moisture in this treatment was only 40.2%. This was similar to the soil moisture contents obtained from the untreated control plots. Soil moisture in these treatments ranged from 41.2% to 43.2%. No significant differences in the percent volumetric soil moisture existed between any of the residual herbicide treatments on this date. Collectively, the data indicate that dense stands of winter annual weeds present in the untreated control plots and plots treated with a fall-applied non-residual treatment can cause significant reductions in soil moisture content one and three WAP.

Soil temperature. Plots receiving applications of simazine plus 2,4-D at 45 days EPP had soil temperatures ranging from 3 C higher to -1 C lower than the untreated control within each day (Figure 4.1). Differences in soil temperature were variable below 10 C. In general, as soil temperatures increased to 10 C, plots treated with simazine plus 2,4-D had a significantly higher soil temperature than untreated plots. However, when temperatures decreased below 10 C these differences were not present. When soil temperatures remained above 10 C the simazine plus 2,4-D treatment consistently resulted in higher soil temperatures than untreated plots until April 15. After this date, there was only one significant difference in soil temperature between the untreated and herbicide treated plots. This sudden loss in soil temperature differences between the herbicide treated and untreated plots may be explained by soil moisture differences within this same time period. Soil moisture sampling conducted at one WAP fell within this same time period. On this sampling date the 45 day EPP untreated plots had a significantly lower soil moisture content than the 45 day EPP herbicide treated plots. The drier soils of the untreated plots may have allowed them to warm up more rapidly, and, therefore, eliminate any negative impacts that winter annual weeds may have on soil temperature.

Insect Injury. Treatment by application timing interactions were not significant at any of the three sampling dates, therefore, insect injury treatment means were averaged across timings to illustrate significant differences in treatments. At the V2 sampling date there was a significant difference in corn flea beetle and lepidopteran injury between the herbicide treated and untreated plots (Figure 4.2). The untreated plots had only 32% corn flea beetle damage and 9% lepidopteran injury, while corn flea beetle damage in the herbicide treated plots ranged from 72% to 76% and lepidopteran injury ranged from 14% to 18%. These results suggest that both groups of insects were either utilizing various winter annual weed species present within the untreated plots as primary feeding hosts, or the winter annual weeds present within these plots were acting as physical obstructions preventing feeding by these insects on the developing corn crop. However, in the herbicide treated plots the limited presence of winter annual weeds left the developing corn crop fully exposed and limited the host availability of these insects, thereby leading to an increase in corn flea beetle and lepidopteran injury when compared to the untreated control.

At the V4 sampling date there was also a significant difference between the herbicide treated and untreated plots in corn flea beetle and lepidopteran injury (Figure 4.2). The untreated plots again exhibited a lower degree of corn flea beetle injury than the herbicide treated plots. Corn flea beetle damage was 56% in the untreated while injury in the herbicide treated plots ranged from 72% to 79%. Lepidopteran injury values in the herbicide treated plots were fairly consistent between the V2 and V4 sampling dates. However, lepidopteran injury in the untreated plots displayed almost a 2.5 fold increase from the V2 to V4 sampling dates. Injury from this class of insects was 22% at the V4 stage, which was significantly higher than any of the three herbicide treatments. Senescence of winter annual weeds and crop developmental rate may have caused this significant increase in lepidopteran injury. Insect pests within this classification may have been forced off of possible winter annual weed hosts due to natural plant senescence. This would suggest that lepidopteran injury in the untreated would be similar to that observed in the herbicide treatments. The slowed development of corn within the untreated plots, which was caused by intense weed competition, may explain the significantly higher lepidopteran injury observed in untreated plots. The younger more vulnerable corn plants present within the untreated plots are likely to have attracted a higher number of lepidopteran pests, thereby causing a significantly higher amount of lepidopteran injury when compared to the herbicide treated plots.

Approximately 10 days prior to the V6 sampling date in both 2005 and 2006 a post application of atrazine plus mesotrione plus nicosulfuron plus rimsulfuron was broadcast over the entire trial. This postemergence treatment, designed for complete weed removal, was likely a major factor in the differences in corn flea beetle and lepidopteran injury observed at the V6 sampling date (Figure 4.2). Corn flea beetle damage at this stage was similar for all treatments. Differences in corn flea beetle damage previously noted between herbicide treated and untreated plots were negated due to complete weed removal. Removal of all weed species also had a major impact on lepidopteran injury. The untreated exhibited 40% lepidopteran injury, which was significantly higher than the herbicide treatments, and almost two times higher than either of the residual herbicide treatments. The removal of dense stands of winter and summer annual weeds present in the untreated plots coupled with the slow crop developmental rate is likely the cause of this increase in lepidopteran injury.

Overall, an early spring treatment of simazine plus 2,4-D did increase soil temperatures compared to the untreated control. This is contradictory to the findings of Krausz et al. (2003). However, it appears that this difference may be influenced by soil moisture content. As soil moisture content decreases, so does the soil temperature differential between weed-free plots and those with dense stands of winter annual weeds. The potential shading effect caused by these winter annual weeds is negated when there is a negative soil moisture difference present between the untreated and herbicide treated plots. Overall, our soil moisture data suggests that the presence of winter annual weeds can have a significant impact on soil moisture content just after planting. Dense stands of winter annual weeds left uncontrolled (either in untreated plots or those treated with a non-residual herbicide in the fall) can cause substantial reductions in soil moisture. In general, insect injury data indicates that delaying a burndown herbicide application until after planting may have little influence on overall corn flea beetle injury, however, delayed applications may lead to more severe lepidopteran damage at the V6 corn stage. Based on the results of this study, applying a herbicide in the fall or early spring to increase soil temperatures and drying before planting may provide limited value. However, making fall or early spring residual herbicide applications can lead to lower lepidopteran injury well after planting.

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Table 4.1. Herbicide application and planting information for the central and northwest Missouri field experiments conducted in 2004-2005 and 2005-2006.

	Central		Northwest	
	2004-2005	2005-2006	2004-2005	2005-2006
Application dates				
Fall	December 3	November 7	December 2	November 10
45 EPP	March 2	February 28	March 14	March 2
30 EPP	March 16	March 15	March 28	March 14
7 EPP	April 12	April 13	April 20	April 10
Soil temperature at application[a]				
Fall	4.4	12.8	5.6	9.4
45 EPP	6.1	11.1	5.6	4.4
30 EPP	14.4	8.9	11.1	6.1
7 EPP	13.9	15.6	15.6	21.1
Planting dates	April 19	April 20	May 2	April 18

[a]Soil temperature in degrees Celsius taken at a 5 cm depth.

Table 4.2. Total monthly precipitation and maximum and minimum air temperatures from March through July at the central and northwest locations in 2005 and 2006.

	Central						Northwest					
	Precipitation		Temperature				Precipitation		Temperature			
	2005	2006	2005		2006		2005	2006	2005		2006	
Month			Max	Min	Max	Min			Max	Min	Max	Min
	----------C----------		------------------mm-------------------				----------C-----------		------------------mm------------------			
March	24	92	26	-7	25	-5	19	54	23	-9	24	-6
April	92	52	7	-1	31	0	80	115	26	-1	32	0
May	78	81	30	1	32	6	115	42	31	0	33	6
June	91	96	34	14	32	13	165	72	34	14	34	13
July	11	77	39	14	38	14	30	98	36	13	37	15
Total[a]	342	399	--	--	--	--	472	382	--	--	--	--

[a]Total rainfall from March 1 to July 31.

Table 4.3. Influence of fall and early spring herbicide applications on the percent volumetric soil moisture content at the central and northwest locations one and three weeks after planting.[a]

Timing	Treatment[b]	Rate[c]	Weeks after Planting One	Weeks after Planting Three
		g ai/ha	--% Volumetric Soil Moisture--	
Fall	Simazine + 2,4-D	1120 + 542	53.4	47.9
	Rimsulfuron + thifensulfuron + 2,4-D	13 + 7 + 542	52.4	48.3
	Glyphosate + 2,4-D	1120 + 542	48.0	40.2
	Untreated	----	37.8	42.0
45EPP	Simazine + 2,4-D	1120 + 542	51.6	46.6
	Rimsulfuron + thifensulfuron + 2,4-D	13 + 7 + 542	53.8	48.6
	Glyphosate + 2,4-D	1120 + 542	54.0	49.7
	Untreated	----	38.9	43.2
30EPP	Simazine + 2,4-D	1120 + 542	52.2	48.3
	Rimsulfuron + thifensulfuron + 2,4-D	13 + 7 + 542	49.9	50.8
	Glyphosate + 2,4-D	1120 + 542	52.7	48.2
	Untreated	----	38.0	41.2
7EPP	Simazine + 2,4-D	1120 + 542	47.1	49.1
	Rimsulfuron + thifensulfuron + 2,4-D	13 + 7 + 542	44.9	47.5
	Glyphosate + 2,4-D	1120 + 542	48.7	50.0
	Untreated	----	39.4	43.1
LSD (0.05)[d]			4.6	4.2

[a] EPP, early preplant.
[b] All treatments containing simazine and rimsulfuron plus thifensulfuron included crop oil concentrate at 1% v/v.
[c] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.
[d] LSD applies to all treatment by timing comparisons within a column.

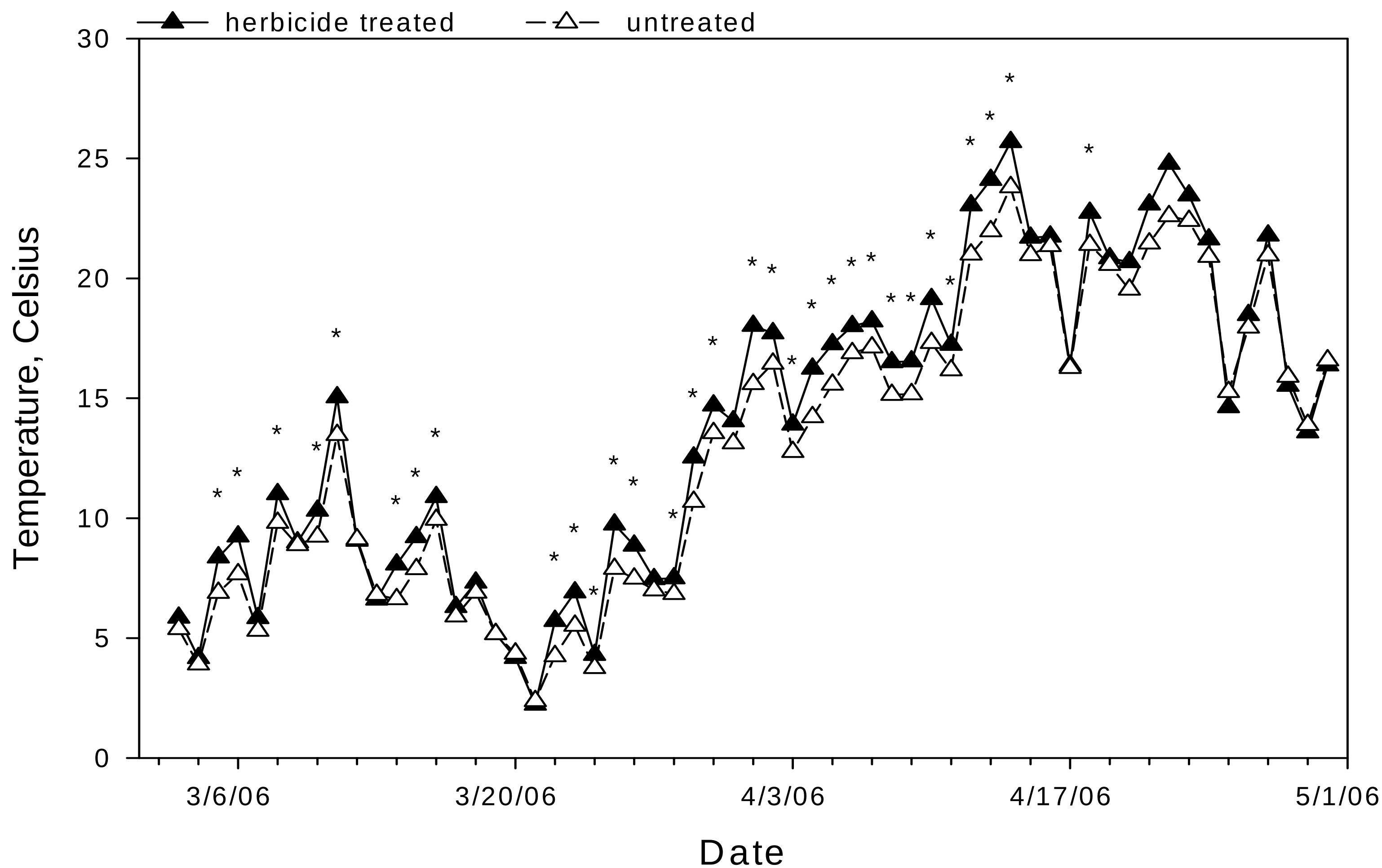

Figure 4.1. Comparison of herbicide treated (simazine+2,4-D) and untreated soil temperatures from both locations. Measurements began on March 1, 2006 and ended May 1, 2006. Asterisks indicate significant differences ($P < 0.05$) in soil temperature when compared within each day.

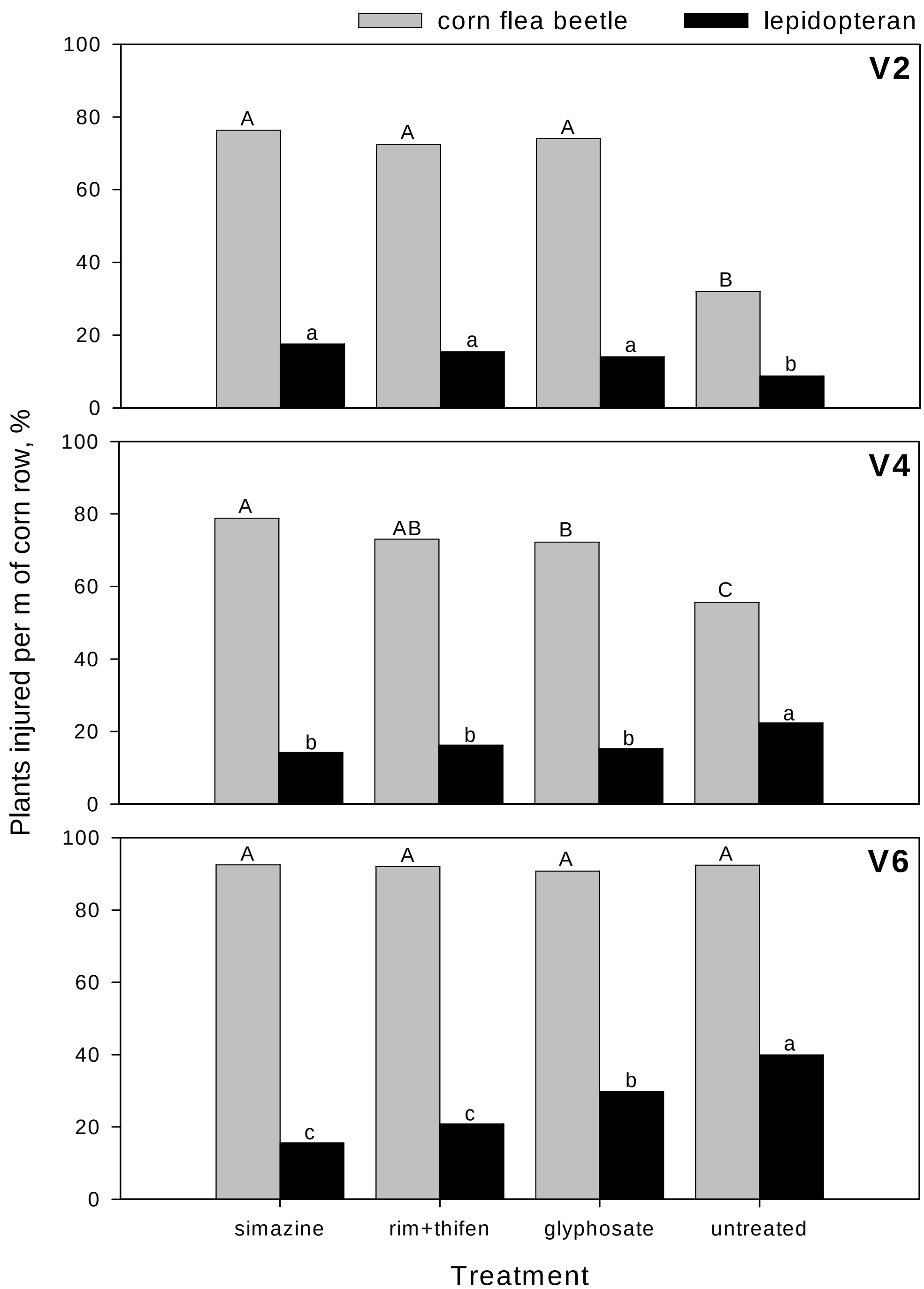

Figure 4.2. Impact of fall and spring herbicide applications on percent corn injury at the V2, V4, and V6 growth stages from corn flea beetle (*Chaetocnema pulicaria*) and lepidopteran insects at the central location in 2005 and 2006. Rim+thifen, rimsulfuron plus thifensulfuron. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment by timing interactions were not significant, therefore, treatment means were averaged across timings. Treatment means with different upper-case letters indicate significant differences ($P < 0.05$) in corn flea beetle injury. Treatment means with different lower-case letters indicate significant differences ($P < 0.05$) in lepidopteran injury.

CHAPTER V

Influence of Fall and Early Spring Herbicide Applications on Winter and Summer Annual Weed Populations in No-Till Corn[1]

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Abstract: Recent trends in agricultural practices have led to an increase in winter annual weed infestations. Field experiments were initiated at two Missouri locations in the fall of 2004 and 2005 to compare the efficacy of fall and early spring herbicide applications on winter and summer annual weed populations in no-till corn. Both experiments received applications of simazine plus 2,4-D, rimsulfuron plus thifensulfuron plus 2,4-D, and glyphosate plus 2,4-D in the fall, 45 days prior to planting (45 days EPP), 30 days prior to planting (30 days EPP), and seven days prior to planting (7 days EPP). Weed control ratings conducted one week after planting (WAP) revealed good control of most winter annual weed species from fall applications of simazine plus 2,4-D and rimsulfuron plus thifensulfuron plus 2,4-D. Glyphosate plus 2,4-D applied in the fall provided greater than 98% control of henbit and common chickweed, which primarily germinated in the early fall. However, this treatment provided only 53% control of field pennycress, which exhibited a significant degree of late fall or early spring germination. In general, summer annual weed control five WAP increased as the time between application and planting decreased. Common waterhemp control was less than 48% from all treatments applied at

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the first three application timings. However, control improved with all treatments applied at 7 days EPP. All spring residual treatments provided greater than 79% giant foxtail and Pennsylvania smartweed control. Measurements of weed biomass collected five WAP revealed greater amounts of biomass as a result of treatments applied in the fall. Emergence counts conducted from early March to five WAP revealed differences in common waterhemp and giant foxtail emergence between the four treatments and application timings. Emergence of common waterhemp and giant foxtail was significantly lower in the two residual treatments when compared to the untreated. Total emergence of these species was also significantly lower in the 30 and 7 day EPP application timings than in the fall timing. The results of this study suggest that fall residual herbicide applications should be used to obtain high levels of winter annual weed control at planting. However, if maximum summer annual weed control is desired five WAP, a 7 day EPP residual herbicide application should be used.

Nomenclature: Glyphosate; rimsulfuron; simazine; thifensulfuron; 2,4-D; annual bluegrass, *Poa annua* L. #[3] POAAN; annual fleabane, *Erigeron annuus* (L.) Pers. # ERIAN; common chickweed, *Stellaria media* (L.) Vill. # STEME; common waterhemp, *Amaranthus rudis* Sauer # AMATA; corn speedwell, *Veronica arvensis* L. # VERAR; field pennycress, *Thlaspi arvense* L. # THLAR; giant foxtail, *Setaria faberi* Herrm. # SETFA; henbit, *Lamium amplexicaule* L. # LAMAM; giant ragweed, *Ambrosia trifida* L. # AMBTR; Pennsylvania smartweed, *Polygonum pensylvanicum* L. # POLPY; pinnate

[3] Letters following this symbol are a 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.

tansymustard, Descurainia pinnata (Walt.) Britt. # DESPI; corn, *Zea mays* L. 'Pioneer 34B23'.

Additional index words: Fall herbicide applications, herbicide application timing, no-till, weed biomass, weed emergence, winter annuals.

Abbreviations: EPP, early preplant; rim+thifen, rimsulfuron plus thifensulfuron; WAP, weeks after planting.

INTRODUCTION

Winter annual weeds can be classified as plants that germinate in the fall or winter, produce seed in the spring, and die by midsummer (Monaco et al. 2002). These weeds are able to survive winter climates by photosynthesizing at low temperatures and light intensities (Regehr and Bazzaz 1976). The ability of these plants to become established in the fall and develop into dense canopies early in the spring can make them problematic. Winter annual weeds can interfere with planting equipment, provide alternative hosts for soybean cyst nematode (*Heterodera glycines* Ichinohe) and insect pests, and can actively compete with the developing crop (Buhler 1995; Creech et al. 2005; Dahlke et al. 2001; Kremer 2005; Venkatesh et al. 2000). Due to their accelerated growth early in the spring these weeds can also become difficult to control with herbicides applied just before corn or soybean planting (Kapusta 1979; Wilson et al. 1985).

Winter annual weed infestations have become more widespread in recent years (Hahn et al. 2002; Krausz et al. 2003). Many scientists have attributed this to four factors: 1) shifts from conventional tillage systems to no-till, 2) widespread adoption of glyphosate-resistant crops, 3) increased usage of glyphosate and a subsequent decrease in the use of soil-applied residual herbicides, and 4) the relatively mild winters experienced in recent years (Buhler 2002; Güeli and Smeda 2002; Kremer 2005; Webb 2005). For example, in 2000, approximately 14 million acres were planted to no-till corn in the U.S. By 2004, however, this area increased to almost 16 million acres (CTIC 2005). Similarly, in 1996, glyphosate was only applied on four percent of the total U.S. corn acreage (USDA 1997). By 2005, this treated area was over eight times larger at 33% (USDA 2006). Conversely, the use of preemergent herbicides such as atrazine and metolachlor have decreased over this period of time. In 1996, atrazine and metolachlor were used on 71% and 30% of the total U.S. corn acreage, respectively (USDA 1997). Applications of atrazine decreased to 66% of the total corn area in 2005, while combined usage of metolachlor and s-metolachlor on corn equaled 25% (USDA 2006).

Fall herbicide applications are directed towards the removal of winter annual weed species. They offer producers the benefit of reducing spring workloads, while targeting winter annual weeds at a more optimal growth stage (Krausz et al. 2003; Hasty et al. 2004). Herbicide applications are made in the fall in order to try and eliminate the need for a spring burndown application prior to planting. Many residual herbicide treatments applied in the fall have proven to be effective at controlling numerous winter annual weed species (Lee and Witt 2001; Hasty et al. 2001; Krausz et al. 2003). However, control of summer annual weed species with these treatments has been inconsistent. Stougaard et al. (1984) obtained season-long weed control from fall applications of cyanazine plus oryzalin in areas with low weed densities. Conversely, Young et al.

(2002) reported variable control of giant foxtail, Pennsylvania smartweed, and common ragweed (*Ambrosia artemisiifolia* L.) with fall applications of residual corn herbicides.

Other researchers have also studied the effects of applying a non-residual herbicide treatment in the fall on winter and summer annual weed populations. Krausz and Young (2005) observed excellent control of henbit, common chickweed, and smallflower buttercup (*Ranunculus abortivus* L.) with fall glyphosate applications. However, poor control of giant ragweed and giant foxtail was observed with this treatment. Similarly, Hasty et al. (2004) reported that fall applications of glyphosate plus 2,4-D provided good control of common chickweed, henbit, and shepherd's-purse. However, this treatment provided poor control of later-emerging winter annuals such as purple deadnettle (*Lamium purpureum* L.) and cressleaf groundsel (*Senecio glabellus* Poir.), as well as the summer annuals common ragweed, common lambsquarters (*Chenopodium album* L.), and common waterhemp.

Though the impacts of applying a non-residual herbicide treatment in the fall have been examined in detail, few studies have focused on determining the earliest spring application timing which provides complete removal of winter annual weed populations. Similarly, few studies have focused on determining the optimal application timing of residual corn herbicide treatments, which supply the most consistent winter and summer annual weed control while incorporating the cultural advantages of fall herbicide applications. Therefore, the objectives of these field experiments were to 1) evaluate the efficacy of fall versus various early spring herbicide application timings on winter annual weed populations and the emergence of summer annual weed seedlings and 2) examine differences in weed control and emergence obtained with residual and non-residual herbicide treatments applied at each of these application timings.

MATERIALS AND METHODS

Field experiments were established at two Missouri locations in the fall of 2004 and 2005. One site was located in central Missouri at the University of Missouri Bradford Research and Extension Center, while the other was located in northwest Missouri near St. Joseph. Sites were selected based on the presence of soybean residue and dense infestations of winter annual weeds. The soil type at the central Missouri location in 2004 and 2005 was a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs). This site had a pH of 5.8 with 1.8% organic matter in 2004. In 2005, this location had a pH of 6.3 with 2.1% organic matter. At St. Joseph the soil type was a Colo silty clay loam (fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) in both 2004 and 2005. This site had a pH of 6.2 with 2.9% organic matter in 2004. In 2005, this location had a pH of 6.1 with 2.4% organic matter.

In all experiments, the experimental design consisted of a randomized complete block with a factorial arrangement of four treatments and four application timings, and four replications. All plots were 6 by 14 m in size. The four treatments consisted of simazine plus 2,4-D at 1120 plus 542 g ai/ha, rimsulfuron plus thifensulfuron plus 2,4-D at 13 plus 7 plus 542 g ai/ha, glyphosate plus 2,4-D at 1120 g ae/ha plus 542 g ai/ha, and an untreated control. All three herbicide treatments were applied at four different timings: fall (mid-November), 45 days prior to planting (early March), 30 days prior to planting (mid-March), and seven days prior to planting (early April). Detailed application information is listed in Table 5.1. Additionally, specific precipitation and air temperature information is listed in Table 5.2. Information on weed density and growth stage at each location and application timing is listed in Tables 5.3 and 5.4. Treatments consisting of simazine and rimsulfuron plus thifensulfuron received crop oil concentrate[4] at 1% v/v. Treatments containing glyphosate received ammonium sulfate at 2.9 kg/ha.

All herbicide applications were made with a CO_2 backpack sprayer set to deliver 140 L/ha at 124 kPa through XR8002[5] flat fan nozzles. Five WAP a post application of atrazine plus mesotrione plus nicosulfuron plus rimsulfuron at 2,240 plus 105 plus 20 plus 10 g ai/ha was broadcast over each trial with a tractor-mounted sprayer. This treatment also contained crop oil concentrate at 1% v/v and 28% urea ammonium nitrate fertilizer[6] at 3.5% v/v.

At all locations, Pioneer '34B23' was planted in mid to late April into a no-tillage seedbed which was planted to soybean the previous year. Seed was planted in 76 cm rows at a density of 71,000 seeds/ha.

Weed control was visually assessed at one and five WAP using a scale of 0 to 100 (0 indicating no injury and 100 representing complete plant death). Five WAP weed biomass, consisting of both winter and summer annual weeds, was harvested from two 0.5 m^2 areas randomly selected within each plot. All weed species, including senesced winter annuals, within this area were cut off at ground level. The plant material was then dried for four days at 60 C and dry weights were recorded.

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[4] Relay brand crop oil concentrate, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

[5] Teejet Spraying Systems Co, North Avenue, Wheaton, IL 60189.

[6] Urea ammonium nitrate fertilizer containing 28% nitrogen obtained in bulk, MFA Inc., 201 Ray Young Drive, Columbia, MO 65201.

Weed seedling emergence was monitored at each location by establishing two permanent 0.5 m^2 quadrats within each plot. These quadrats were evaluated at two-week intervals beginning in early March and ending five WAP. The number of emerged winter and summer annual weed seedlings within each quadrat were counted and recorded. Emerged seedlings were removed from each quadrat after they had been counted.

Winter and summer annual weed emergence was highly variable between years, locations, and individual experiments. Common waterhemp and giant foxtail were the only two weed species that were consistent across all four environments. As a result, weed species other than common waterhemp and giant foxtail were grouped into their respective growth habits, either winter or summer annuals. Data was then summarized across all counting dates to give an accumulated emergence of common waterhemp, giant foxtail, and winter and summer annual weeds from early March to five WAP. Treatment by application timing interactions for the emergence data were not significant, therefore, treatment means were averaged across timings to display significant differences in treatments. Means for application timing were also averaged across treatments to display significant differences in weed emergence between timings.

Data analysis. All data were analyzed using the Proc Mixed procedure in SAS (2005). As suggested by Carmer et al. (1989), each year-location combination was considered an environment sampled at random. Fixed effects in the model were herbicide treatment and application timing. Random effects included environment, replications (nested within environments), and all interactions with environment and replications. Considering environments at random enables inferences about the treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003; Hasty et al. 2004). Individual treatment differences were detected by using Fisher's protected LSD at $P < 0.05$. Weed control data were transformed using arcsine of the square root. Transformation did not alter data interpretation, therefore, nontransformed weed control means are presented. Square root transformations did improve the model for both weed biomass and weed emergence data. Analyses for these data were performed on the transformed means. Means were then back transformed for data presentation.

RESULTS AND DISCUSSION

Winter Annual Weed Control One WAP. Control of all six winter annual weed species one week after planting was highly influenced by application timing (Table 5.5). Henbit control from all three treatments applied at the 7 day EPP application timing was reduced when compared to the other three previous timings. The presence of henbit in the flowering stage at this application timing likely translated into its reduced control. Sosebee and Dahl (1991) reported a similar trend in control with annual weed species in the reproductive phase. Control of henbit from all other treatments and application timings was greater than 90% except simazine plus 2,4-D applied 30 days EPP. Krausz et al. (2003) reported similar control of henbit with fall applications of simazine and rimsulfuron plus thifensulfuron. Common chickweed control was greater than 84% from all treatments except simazine plus 2,4-D applied 30 days EPP. Once again, this treatment provided a lower level of control than the same treatment applied in the fall and 45 days EPP.

Control of field pennycress was excellent from all treatments except glyphosate plus 2,4-D applied in the fall. This treatment provided only 53% control of field pennycress.

This lower level of control observed with fall-applied glyphosate plus 2,4-D indicates that significant field pennycress emergence occurred after the fall application timing.

Annual fleabane control was similar to that of henbit. Control from all three treatments applied in the fall, 45, and 30 days EPP was greater than 87%. However, control from all three treatments applied at 7 days EPP ranged from only 20 to 76%. Annual fleabane was in the flowering stage at the 7 day EPP application timing, which likely explains the lower level of control obtained from these treatments.

Control of annual bluegrass was excellent from all applications of glyphosate plus 2,4-D. Rimsulfuron plus thifensulfuron plus 2,4-D also provided excellent annual bluegrass control when applied in the fall, 45 days EPP, and 30 days EPP. However, when annual bluegrass was in the heading stage at 7 days EPP, rimsulfuron plus thifensulfuron plus 2,4-D provided only 58% control of annual bluegrass one WAP. Simazine plus 2,4-D, however, only provided adequate control of annual bluegrass at the fall application timing. Control at the 45 day EPP timing decreased to 56% control, while at the 30 and 7 day EPP application timings control was only 15% and 3% respectively.

Corn speedwell control was greater than 91% for all simazine plus 2,4-D and glyphosate plus 2,4-D treatments. Control from all rimsulfuron plus thifensulfuron plus 2,4-D treatments, however, was relatively poor. These treatments ranged from only 23 to 65% control with the 7 day EPP treatment providing the lowest level of corn speedwell control.

Summer Annual Weed Control Five WAP. Control of common waterhemp five weeks after planting was relatively poor from all treatments (Table 5.6). Simazine plus 2,4-D and rimsulfuron plus thifensulfuron plus 2,4-D applied at 7 days EPP were the only treatments that provided greater than 70% control of common waterhemp. Glyphosate plus 2,4-D applied at 7 days EPP was the only non-residual treatment to provide greater than 60% common waterhemp control.

Giant foxtail control was reduced with all three herbicide treatments applied in the fall. Control from both residual herbicide treatments applied at the spring application timings, however, was greater than 79%. The only non-residual treatment to provide greater than 70% control of giant foxtail was glyphosate plus 2,4-D applied 7 days EPP.

Giant ragweed control was highly variable ranging from 0 to 99%. Relatively poor control of giant ragweed was obtained from all treatments applied in the fall, 45 days EPP, and 30 days EPP. Glyphosate plus 2,4-D applied in the fall 45, and 30 days EPP provided essentially no control of giant ragweed. Simazine plus 2,4-D applied 30 days EPP was the only early spring treatment to provide at least 60% giant ragweed control. All treatments applied 7 days EPP, however, provided excellent control of giant ragweed.

Pennsylvania smartweed control was highly influenced by herbicide treatment and application timing. Glyphosate plus 2,4-D applied in the fall, 45, and 30 days EPP provided less than 26% control of Pennsylvania smartweed. This increased to 70% control with the 7 day EPP application of glyphosate plus 2,4-D. Control of Pennsylvania smartweed with both residual treatments applied at all three spring application timings was greater than 82%. However, Pennsylvania smartweed control with fall-applied residual treatments was less than 75%.

Weed Biomass. When compared within herbicide treatments, the fall application timing resulted in more weed biomass five WAP than any of the spring timings (Figure 5.1). Fall applications of glyphosate plus 2,4-D resulted in similar amounts of weed biomass as the untreated control. This is likely a reflection of the non-residual nature of glyphosate, which allowed for the establishment of spring germinating weed species. When compared to the two residual treatments, glyphosate plus 2,4-D resulted in significantly higher amounts of weed biomass at each application timing, except at 7 days EPP. Both residual treatments produced similar amounts of weed biomass at all four application timings. The smallest amount of weed biomass was observed with both residual treatments applied at either of the spring timings and glyphosate plus 2,4-D applied at 7 days EPP.

Weed Emergence. The emergence of total winter annual weeds from early March to five WAP was minimal. Emergence of these weeds ranged from zero to eight plants per 0.5 m^2. When averaged across all four timings, applications of the two residual herbicide treatments resulted in significantly less winter annual weed emergence than glyphosate plus 2,4-D and untreated plots (Table 5.7). In a similar comparison, winter annual weed emergence in the non-residual, glyphosate plus 2,4-D plots was not significantly different than winter annual weed emergence in the untreated. When comparing across all four treatments, the emergence of total winter annual weeds was greatest with the fall application timing (Table 5.8). Emergence of winter annuals was significantly reduced when herbicide applications were made at one of the three spring timings rather than in the fall. This data indicates that significant winter annual weed emergence can occur after a traditional fall herbicide application.

The emergence of common waterhemp was also significantly influenced by herbicide treatment and application timing. Across all four timings, emergence of common waterhemp was significantly lower with the two residual herbicide treatments compared to the untreated control (Table 5.7). Common waterhemp emergence in plots treated with glyphosate plus 2,4-D was not significantly different than those treated with a residual herbicide treatment or those left untreated. When averaged across all four treatments, common waterhemp emergence was greatest with the fall application timing (Table 5.8). Herbicide applications made at the 30 and 7 day EPP timings caused a significant reduction in common waterhemp emergence when compared to the fall timing. However, emergence at the 45 day EPP timing was not significantly different than the fall application, or the 30 and 7 day EPP applications.

Herbicide treatment and application timing had a similar impact on total giant foxtail emergence as it did on total common waterhemp emergence. When averaged across all four timings, total giant foxtail emergence was greatest in the untreated plots (Table 5.7). Applications of the two residual herbicide treatments caused a significant reduction in giant foxtail emergence when compared to the untreated. Applications of glyphosate plus 2,4-D resulted in similar giant foxtail emergence as the untreated and two residual herbicide treatments. Across all four treatments, the three spring application timings resulted in similar giant foxtail emergence, but significantly less than the fall application timing (Table 5.8). This data suggests that giant foxtail and common waterhemp emergence can be reduced by applying a residual herbicide treatment at one of the spring application timings.

Overall, our results suggest that fall applications of residual herbicide treatments can provide a clean seedbed for planting. However, control of summer annual weed species that emerge later in the spring is inconsistent with these treatments. Seven day EPP herbicide applications offer more favorable summer annual weed control five WAP, yet the control of winter annual weed species one WAP with these treatments is inadequate. Thirty and 45 day EPP residual applications offer more favorable winter annual weed control one WAP than 7 day EPP treatments. Residual treatments applied at 30 and 45 days EPP also improve summer annual weed control five WAP when compared to fall residual applications. However, these early spring treatments still provide relatively poor control of common waterhemp and giant ragweed five WAP. Therefore, the benefits of applying a residual herbicide treatment in the early spring over the fall are somewhat limited. Based on the results of this study, fall residual herbicide applications should be used to obtain high levels of winter annual weed control at planting. However, if maximum summer annual weed control is desired well after planting, a 7 day EPP residual herbicide application should be used.

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Table 5.1. Herbicide application and planting information for the central and northwest Missouri field experiments conducted in 2004-2005 and 2005-2006.

	Central		Northwest	
	2004-2005	2005-2006	2004-2005	2005-2006
Application dates				
Fall	December 3	November 7	December 2	November 10
45 EPP	March 2	February 28	March 14	March 2
30 EPP	March 16	March 15	March 28	March 14
7 EPP	April 12	April 13	April 20	April 10
Soil temperature at application[a]				
Fall	4.4	12.8	5.6	9.4
45 EPP	6.1	11.1	5.6	4.4
30 EPP	14.4	8.9	11.1	6.1
7 EPP	13.9	15.6	15.6	21.1
Planting dates	April 19	April 20	May 2	April 18

[a]Soil temperature in degrees Celsius taken at a 5 cm depth.

Table 5.2. Total monthly precipitation and maximum and minimum air temperatures from March through July at the central and northwest locations in 2005 and 2006.

	Central						Northwest					
	Precipitation		Temperature				Precipitation		Temperature			
	2005	2006	2005		2006		2005	2006	2005		2006	
Month			Max	Min	Max	Min			Max	Min	Max	Min
	----------C----------		------------------mm------------------				----------C----------		------------------mm------------------			
March	24	92	26	-7	25	-5	19	54	23	-9	24	-6
April	92	52	7	-1	31	0	80	115	26	-1	32	0
May	78	81	30	1	32	6	115	42	31	0	33	6
June	91	96	34	14	32	13	165	72	34	14	34	13
July	11	77	39	14	38	14	30	98	36	13	37	15
Total[a]	342	399	--	--	--	--	472	382	--	--	--	--

[a]Total rainfall from March 1 to July 31.

Table 5.3. Weed species, density, and stage at application for the central Missouri location in 2004-2005 and 2005-2006.[a,b]

	Central											
	Fall			60EPP			30EPP			7EPP		
Species	Density[c]	Stage[d]	Height[e]	Density	Stage	Height	Density	Stage	Height	Density	Stage	Height
2004-2005												
LAMAM	11	vegetative	1	12	vegetative	2	3	vegetative	2	5	flowering	8
STEME	8	vegetative	1	5	vegetative	3	1	vegetative	3	1	flowering	8
THLAR	3	rosette	5	6	rosette	5	1	rosette	5	8	bolting	10
POAAN	4	vegetative	3	11	vegetative	3	6	vegetative	3	40	heading	8
2005-2006												
LAMAM	16	vegetative	4	10	vegetative	5	6	flowering	8	8	flowering	15
STEME	15	vegetative	5	13	vegetative	6	10	vegetative	8	10	flowering	15
THLAR	3	rosette	3	1	rosette	8	1	bolting	5	1	flowering	33
ERIAN	1	rosette	13	2	rosette	15	2	rosette	15	1	bolting	23
VERAR	2	vegetative	2	8	vegetative	2	7	vegetative	2	5	flowering	5

[a] LAMAM, henbit; STEME, common chickweed; THLAR, field pennycress; POAAN, annual bluegrass; ERIAN, annual fleabane; VERAR, corn speedwell.
[b] EPP, early preplant.
[c] Density denotes the average number of plants per 0.5 m^2
[d] Predominant growth stage of the plant species at the time of application.
[e] Average height of the plant species in cm. For plants in the rosette stage, this measurement indicates diameter of the plant.

Table 5.4. Weed species, density, and stage at application for the northwest Missouri location in 2004-2005 and 2005-2006.[a,b,c]

	Northwest											
	Fall			60EPP			30EPP			7EPP		
Species	Density[d]	Stage[e]	Height[f]	Density	Stage	Height	Density	Stage	Height	Density	Stage	Height
2004-2005												
LAMAM	125	vegetative	3	104	vegetative	3	93	vegetative	5	62	flowering	15
THLAR	30	rosette	8	26	rosette	8	27	bolting	5	22	flowering	61
2005-2006												
LAMAM	56	vegetative	2	24	vegetative	3	24	vegetative	3	21	flowering	5
DESPI	0	---	--	1	rosette	4	2	rosette	5	1	bolting	13

[a] LAMAM, henbit; THLAR, field pennycress; DESPI, pinnate tansymustard.
[b] EPP, early preplant.
[c] -- indicates species that were not present at the time of application.
[d] Density denotes the average number of plants per 0.5 m^2
[e] Predominant growth stage of the plant species at the time of application.
[f] Average height of the plant species in cm. For plants in the rosette stage, this measurement indicates diameter of the plant.

Table 5.5. Winter annual weed control one week after corn planting from fall, 45, 30, and 7 day EPP herbicide applications at the central and northwest Missouri locations in 2005 and 2006.[a]

			Weed species[b]					
Timing	Treatment[c]	Rate[d]	LAMAM	STEME	THLAR	ERIAN	POAAN	VERAR
		g ai/ha	% control					
Fall	Simazine	1120	99	99	90	97	98	99
	Rimsulfuron + thifensulfuron	13 + 7	99	99	97	92	99	65
	Glyphosate	1120	98	99	53	99	98	99
45EPP	Simazine	1120	92	96	98	98	56	99
	Rimsulfuron + thifensulfuron	13 + 7	91	99	99	97	99	60
	Glyphosate	1120	97	99	94	99	98	99
30EPP	Simazine	1120	77	74	99	87	15	99
	Rimsulfuron + thifensulfuron	13 + 7	92	99	99	94	99	58
	Glyphosate	1120	98	99	99	99	99	91
7EPP	Simazine	1120	58	84	88	20	3	97
	Rimsulfuron + thifensulfuron	13 + 7	67	96	89	29	58	23
	Glyphosate	1120	75	99	97	76	99	99
LSD (0.05)[e]			7	7	5	6	5	7
Environments[f]			4	2	2	1	1	1

[a] EPP, early preplant.

[b] LAMAM, henbit; STEME, common chickweed; THLAR, field pennycress; ERIAN, annual fleabane; POAAN; annual bluegrass; VERAR, corn speedwell.
[c] All treatments included 2,4-D at 542 g ai/ha. All treatments containing simazine and rimsulfuron plus thifensulfuron included crop oil concentrate at 1% v/v.
[d] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.
[e] LSD applies to all comparisons within a species.
[f] Number of environments in which a species was present.

Table 5.6. Summer annual weed control at five weeks after planting from fall, 45, 30, and 7 day EPP herbicide applications at the central and northwest Missouri locations in 2005 and 2006.[a]

			Weed species[b]			
Timing	Treatment[c]	Rate[d]	AMATA	SETFA	AMBTR	POLPY
		g ai/ha	-----% control-----			
Fall	Simazine	1120	23	66	34	64
	Rimsulfuron + thifensulfuron	13 + 7	27	71	23	75
	Glyphosate	1120	10	52	0	18
45EPP	Simazine	1120	30	84	40	95
	Rimsulfuron + thifensulfuron	13 + 7	38	87	46	95
	Glyphosate	1120	20	56	0	26
30EPP	Simazine	1120	48	87	60	91
	Rimsulfuron + thifensulfuron	13 + 7	44	79	33	82
	Glyphosate	1120	29	69	10	23
7EPP	Simazine	1120	73	86	99	99
	Rimsulfuron + thifensulfuron	13 + 7	70	86	99	95
	Glyphosate	1120	61	77	99	70
LSD (0.05)[e]			12	6	15	9
Environments[f]			3	2	1	1

[a] EPP, early preplant.

[b] AMATA, common waterhemp; SETFA, giant foxtail; AMBTR; giant ragweed; ERIAN, annual fleabane; POLPY, Pennsylvania smartweed.
[c] All treatments included 2,4-D at 542 g ai/ha. All treatments containing simazine and rimsulfuron plus thifensulfuron included crop oil concentrate at 1% v/v.
[d] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.
[e] LSD applies to all comparisons within a species.
[f] Number of environments in which a species was present.

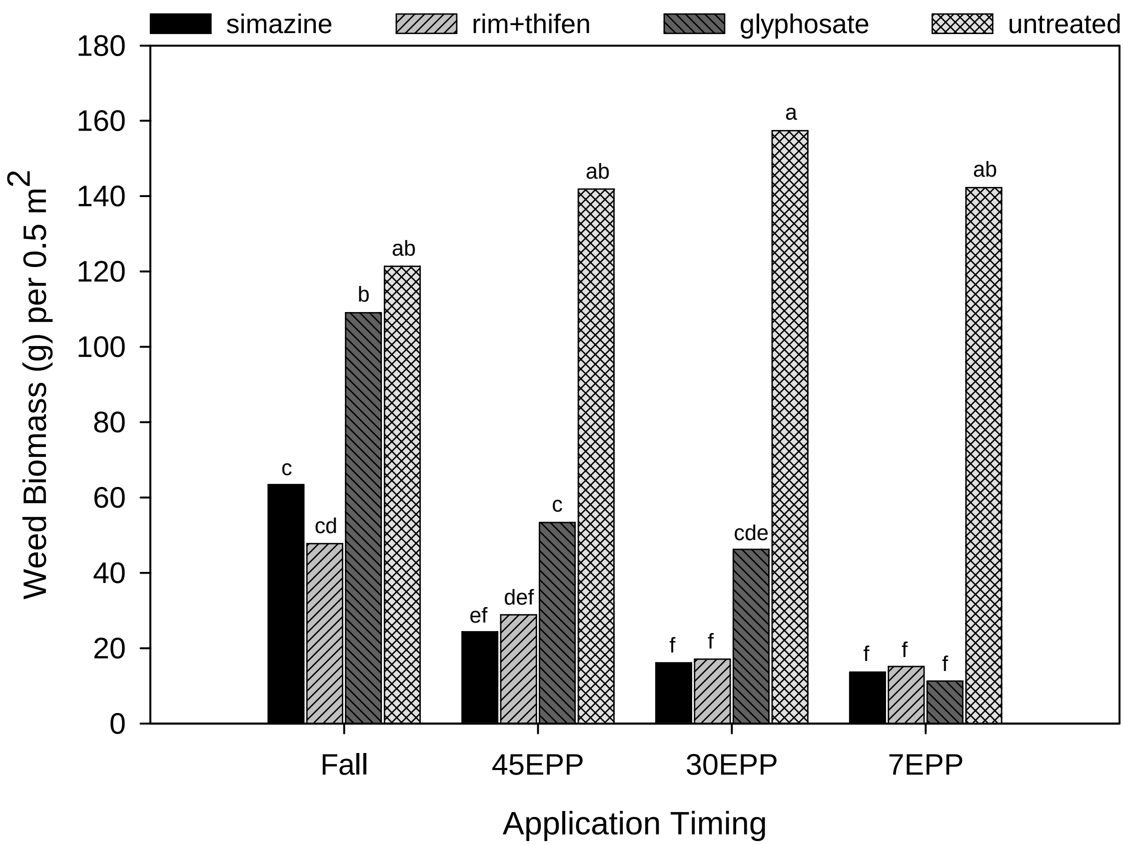

Figure 5.1. Impact of fall and early spring herbicide applications on total weed biomass five weeks after planting. Rim+thifen, rimsulfuron plus thifensulfuron. All herbicide treatments also received 2,4-D at 542 g ai/ha. Treatment means with different letters indicate significant differences ($P < 0.05$) in total weed biomass and should be used for all comparisons across timings and treatments.

Table 5.7. Influence of herbicide treatment on total emergence of winter annual weed species, common waterhemp, and giant foxtail at the central and northwest Missouri locations in 2005 and 2006.[a]

		Weed species or group[b]		
Treatment[c]	Rate[d]	Winter annuals	AMATA	SETFA
	g ai/ha	----------------------emerged plants per 0.5 m^2---------------------		
Simazine	1120	1 b	95 b	6 b
Rimsulfuron + thifensulfuron	13 + 7	1 b	98 b	7 b
Glyphosate	1120	4 a	116 ab	8 ab
Untreated	---	3 a	121 a	11 a

[a] Treatment by application timing interactions were not significant, therefore, treatment means were averaged across timings. Treatment means with different letters indicate significant differences ($P < 0.05$) in total emergence within a species or group.
[b] AMATA, common waterhemp; SETFA, giant foxtail.
[c] All treatments included 2,4-D at 542 g ai/ha. All treatments containing simazine and rimsulfuron plus thifensulfuron included crop oil concentrate at 1% v/v.
[d] Glyphosate rates are given in g ae/ha. All other herbicide rates are given in g ai/ha. Ammonium sulfate was added to all glyphosate treatments at 2.9 kg/ha.

Table 5.8. Influence of application timing on total emergence of winter annual weed species, common waterhemp, and giant foxtail at the central and northwest Missouri locations in 2005 and 2006.[a]

	Weed species or group[b]		
Timing	Winter annuals	AMATA	SETFA
	-------------------------emerged plants per 0.5 m^2-----------------------		
Fall	8 a	132 a	12 a
45EPP	2 b	119 ab	4 b
30EPP	1 bc	89 b	7 b
7EPP	0 c	90 b	11 a

[a] Treatment by application timing interactions were not significant, therefore, application timing means were averaged across treatments. Means with different letters indicate significant differences ($P < 0.05$) in total emergence within a species or group.
[b] AMATA, common waterhemp; SETFA, giant foxtail.