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Weed growth in conventional and low-input cropping systems

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Weed growth in conventional and low-input cropping systems

by

Rachel Beverly Halbach

A thesis submitted to the graduate faculty
in partial fulfillment of the requirement of the degree of

MASTER OF SCIENCE

Major: Crop Production and Physiology (Weed Science)

Program of Study Committee
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GENERAL INTRODUCTION

Growers have long used crop rotation to their advantage, i.e., earning nitrogen credits by planting legumes, disrupting the life cycle of a pathogen or insect pest by planting non-host crops, and interrupting a weed’s life cycle by varying planting and harvest dates. However, the typical crop rotation in the Midwestern USA only includes one or two crops. The sustainability of such systems has been questioned, as the natural balances created by species interactions in long-term rotations must be replaced with synthetic fertilizers and chemicals (Drinkwater et al. 1998; Pimentel et al. 2005). Researchers have documented many differences between conventional and diverse rotations, including plant growth (Liebman et al. 2004; Menalled et al. 2004), pathogen populations (Dabney et al. 1996; Kirkpatrick and Rothrock 1995), and soil nitrogen content (Pimentel et al. 2005; Smith et al. 2008).

Studies involving crop rotation effects on weed population parameters in corn and soybean have shown that population growth can be reduced when certain crops, especially small grains and forages, are included in the rotation. In a two year study, Heggenstaller and Liebman (2006) observed a decline or no change in population of velvetleaf (*Abutilon theophrasti*) in two, three, and four year rotational systems even though the latter two used 72 and 79% lower herbicide inputs respectively. They hypothesized low fecundity in triticale (*×Triticeosecale* spp.) and low seedling survival and fecundity in alfalfa (*Medicago sativa*) prevented population change in the three- and four-year systems. Schreiber (1992) reported a decrease in densities of giant foxtail (*Setaria faberi*) in years after wheat (*Triticum aestivum*) due to allelopathy of the wheat straw. The different harvest timings of small grains and
forages compared to summer annual crops provide another source of weed control as well (Thurston 1962; Walenta et al. 2002; Melander et al. 2005).

Researchers have compared crop growth and production characteristics in different cropping systems. A four year study showed corn (*Zea mays*) and soybean (*Glycine max*) yields as high or higher in three- and four-year systems versus a two-year system (Liebman et al. 2008). A study started in 1984 also showed higher corn yields when soybeans, oats (*Avena sativa*), or alfalfa were included in the rotation (Mallarino et al. 2006). However, information concerning the impacts of different cropping systems on the growth characteristics of weeds is limited. This knowledge gap is addressed with two experiments that aim to determine if soil quality affects weed emergence, growth, and biomass.

**Thesis Organization**
A literature review precedes a paper that is presented in journal format. The paper describes two studies evaluating the impact of two different cropping systems on emergence, growth, and end-of-season biomass of four weed species. Following the paper are the general conclusions of the studies, literature review citations, and acknowledgements.
LITERATURE REVIEW

Concerns about the sustainability of the corn-soybean cropping system that dominates the Midwestern United States have led to the evaluation of more diversified systems. Monocultures decrease species interactions that are important for nutrient cycling and controlling pest populations, and those natural balances are usually replaced with synthetic fertilizers and pesticides (Drinkwater et al. 1998; Pimentel et al. 2005). Diverse crop rotations provide several important ecosystem services, such as increased weed suppression, which can increase grain yield (Liebman and Dyck 1993). Many studies have focused on the effects of crop rotation on crops themselves, but only a few have researched the rotational effects on weed emergence, fitness characteristics, and population dynamics. Studies have compared weed growth parameters as influenced by tillage (Cardina et al. 2002; Davis et al. 2005; Menalled et al. 2004), crop rotation history (Brainard et al. 2008), compost (Liebman et al. 2004; Menalled et al. 2004), and soil quality (Benech-Arnold et al. 2000; Hansson and Fogelfors 1998; Wedin and Tilman 1996).

Varying management tactics, crop planting dates, crop life cycles, and crop growth habits and competitiveness in a system can be a beneficial approach to managing weeds. The effect of crop diversity on weed population dynamics can be wide-ranging due to the interactions among these factors as well as their interaction with environmental factors (Brainard et al. 2008). Crop diversity may alter resource availability so that the resources are preferentially utilized by crops, therefore increasing stress and mortality factors affecting weeds (Liebman and Gallandt 1997; Liebman and Staver 2001). Potential benefits include greater efficiency of water and nutrient use by crops (Anderson 2005), higher early-season
nitrogen levels, which are positively related to higher corn grain yield (Smith et al. 2008), and reduced incidence of pests (Brust and Stinner 1991; Sumner 1982).

Studies on cropping systems carried out over several years have quantified many weed demographic parameters. For example, Heggenstaller and Liebman (2006) consistently saw greater velvetleaf recruitment in a two year system compared to three- and four-year systems, but observed increased seedling survival and reduced fecundity of velvetleaf in the three- and four-year systems over the two-year system. Despite differences among the demographic parameters evaluated, the annual rate of velvetleaf population change did not differ among the three systems.

Research tends to support the generalization that long-term rotations have more diverse weed communities than monocultures, but have a lower total density of weeds (Buhler et al. 2001; Dorado et al. 1999; Doucet et al. 1999; Liebman and Dyck 1993; Liebman and Staver 2001; Menalled et al. 2001). The inclusion of certain crops in a rotation may alter weed population dynamics. Brainard et al. (2008) observed higher Amaranthus species and common ragweed (Ambrosia artemisiifolia) emergence in a continuous corn rotation versus rotations including winter wheat (Triticum aestivum). Liebman and Dyck (1993) and Schreiber (1992) suggested that allelopathy and an increase in predators and pathogens during the small grain phase were a cause for the changes observed in weed populations. Because of their increased plant density, small grains can provide essential protection for weed seed predators (Davis and Liebman 2003). Other crops, such as red clover (Trifolium pretense), may have similar effects on weed populations through allelopathy and increased predator protection (Liebman and Dyck 1993). Crops grown
previously in a rotation can also impact weed seedbank density and weed emergence, as observed in a vegetable rotation study by Brainard et al. (2008).

Rotations that include crops with different planting and harvest dates add another source of stress to weeds. Including a fall grain crop in the rotation reduced wild oat (*Avena fatua*) populations in spring barley (*Hordeum vulgare*) (Thurston 1962), while growing spring wheat improved control of jointed goatgrass (*Aegilops cylindrica*) (Walenta et al. 2002). Melander et al. (2005) advised that crops planted in the spring will control winter annual weed species while summer annuals are suppressed by planting a fall sown crop.

Weeds that emerge later than the crop have less of an impact on yield than those that emerge with the crop. Hartzler et al. (2004) reported 90% survival of the first cohort of common waterhemp (*Amaranthus rudis*), but survival decreased by 20 to 30% with each delay in emergence corresponding to corn growth stages of VE, V2, V4, and V6. Common waterhemp reduced soybean yield as much as 56% when it emerged with soybean, but did not reduce yield when emergence was delayed as little as two weeks (Bensch et al. 2003). In addition to crop yield, weed biomass and seed production can be affected by weed emergence timing. Steckel and Sprague (2004) found that as common waterhemp emergence was delayed from soybean emergence to growth stages V2 to V3, biomass was reduced by 56%, and as it was delayed from V2 to V3 until V4 to V5, biomass was reduced by 19%. A similar study by Hartzler et al. (2004) showed a 50 to 80% reduction in common waterhemp biomass as emergence was delayed from 14 to 28 days after soybean planting. Giant ragweed (*Ambrosia trifida*) that emerged at or after the V5 corn growth stage had reduced fecundity and competitiveness was reduced below damage thresholds for crop yield loss.
(Harrison et al. 2001). Seed production of common waterhemp declined incrementally as emergence was delayed (Steckel and Sprague 2004) and giant ragweed seed rain was 15-fold greater when plants emerged with corn compared with those that emerged 4 weeks after corn (Harrison et al. 2001).

Many factors within the environment act on seeds and determine their longevity. Animal predators, fungi, bacteria, phytotoxins, and soil properties all affect seed persistence. Mice, ground beetles, slugs, cutworms, crickets, and ants are aboveground predators of weed seeds in agricultural fields (Brust 1994; Brust and House 1988; Cardina and Sparrow 1996; Cromar et al. 1999; Marino et al. 1997; Mittelbach and Gross 1984). Predation rates of 57 and 90% of velvetleaf and giant ragweed seed, respectively, have been observed in cornfields (Cardina and Sparrow 1996; Harrison et al. 2003). Seeds may also be predated prior to being shed onto the soil surface. Giant ragweed seed collected in Ohio was found to be 86% non-viable with 11% of the non-viable seed infested with Cecidomyiidae, Tephritidae, or Curculionidae larvae and the majority of the remaining damaged seed showing evidence of prior insect infestation (Amatangelo 1974). Few have studied the life cycles of insect granivores, so the effect of management practices, such as crop rotation and tillage, on their populations is relatively unknown (Harrison et al. 2001).

Numerous fungi and bacteria influence weed seed dynamics. Okalebo et al. (2008) examined several soils in a greenhouse study and reported that soil from a field observed to suppress velvetleaf produced plants with a biomass of 0.03 g and a leaf area of 5.8 cm$^2$. Plants grown in the same soil after autoclaving produced 0.14 g biomass and a leaf area of 45.2 cm$^2$. They proposed that soil borne pathogens such as *Rhizoctonia solani*, *Pythium* and
*Fusarium* species might have been responsible for the suppressed growth and high mortality of velvetleaf. Kumar et al. (2008) suggested fungi influence the success of seeds after observing greater emergence of fungicide treated corn chamomile (*Anthemis arvensis*) than that of untreated seed.

The use of green manures may increase the populations of soil pathogens that attack weeds. Several studies have shown increased populations of *Rhizoctonia solani*, *Pythium*, *Fusarium*, and *Thielaviopsis* after the incorporation of cover crops (Dabney et al. 1996; Kirkpatrick and Rothrock 1995). Green manure plant tissues may break down into toxic compounds that suppress weeds. For example, *Brassica* species incorporated into the soil, release isothiocyanates, compounds that have been shown to limit growth of velvetleaf, sorghum (*Sorghum bicolor*), and various grass species (Bell and Muller 1973; Wolf et al. 1984).

Compost used to replace synthetic fertilizers may release phytotoxic chemicals into the soil as well as change the soil’s water holding capacity, bulk density, and nutrient composition (Bazzoffi et al. 1998; Gonzalez and Cooperband 2002). All of these factors have been found to affect weed seed germination (Baskin and Baskin 1998; Bazzoffi et al. 1998; Gonzalez and Cooperband 2002; Ligneau and Watt 1995; Marambe and Ando 1992; Ozores-Hampton et al. 1999; Roe et al. 1993). However, Menalled et al. (2005) reported that the addition of compost did not affect the emergence or the viability of yellow foxtail (*Setaria glauca*) or common waterhemp seeds.

The use of compost as a soil amendment can change weed growth and population dynamics. Liebman et al. (2004) found that effects of compost on soil potassium and
phosphorus concentrations increased the height, biomass, and seed production of common waterhemp and velvetleaf in corn. Menalled et al. (2004) observed similar results in soybean with both common waterhemp and soybean stem diameter and height being larger in plots amended with compost versus non-composted plots. Common waterhemp biomass was also greater in composted plots, but weed-free soybean yields were not affected by compost. They concluded that the competitive ability of common waterhemp was greater when compost was applied. Menalled et al. (2004) also suggested that compost could alter the male to female plant ratio of common waterhemp as a larger number of male plants were found in composted plots than non-amended plots. This study concluded that fecundity is altered by compost because smaller plants produced more seeds per gram of vegetative tissue than larger ones.

Ligneau and Watt (1995) showed that emergence of small-seeded species in a greenhouse was reduced by the addition of compost, whereas large-seeded weeds were not affected. Fennimore and Jackson (2003) reported reduced weed emergence in composted plots versus non-composted plots in a vegetable field. They believed it to be due to a negative correlation between the microbial biomass and weed emergence.

Tillage influences weed management through impacts on weed species composition and abundance (Cardina et al. 2002). As the number of tillage operations increase, seeds tend to be more evenly distributed in the soil profile, while reduced-tillage and no-till leaves seed close to the surface. Buhler (1995) found reduced tillage systems had weed communities of species whose seeds survive near or on the soil surface, while weeds whose seeds need burial to break dormancy perform better in conventional tillage systems. Others
have concluded that perennials are more prevalent in reduced tillage systems than conventional tillage due to reproduction by vegetative structures in addition to seed (Barberi et al. 1998; Cardina et al. 1991; Triplett and Lytle 1972).

Tillage practices may also affect weed emergence and growth. Webster et al. (1998) reported a moldboard plow system had cumulative velvetleaf seedbank emergence of 6 to 7% over four years, whereas a no-till system had emergence of 12 to 25%. Common waterhemp emergence was 1.8 times greater (Steckel et al. 2007) and stem diameter was 15% larger in chisel plowed systems versus no-till systems (Menalled et al. 2004). Menalled et al. (2004) also reported that soybean height and stem diameter were influenced by tillage.

Tillage affects weed seed predation on the soil surface. Seed predation has been found to be more frequent in no-till, with 2.3 times more predation occurring in no-till fields versus conventionally tilled fields (Brust and House 1988). Cromar et al. (1999) found 32% of an artificial seedbank was predated upon in a no-till field compared to 24% in a chisel plowed field. Crop residue left on the soil surface in the no-till system provides protection for seed predators, thus promoting predation in those areas (Mittelbach and Gross 1984). Mittelbach and Gross (1984) also showed an inverse relationship between the amount of soil disturbance and the quantity of predation due to differences in seed placement within the soil profile. Cardina et al. (1996), however, found no difference in predation of velvetleaf seeds in a continuous corn study with treatments of no-till and conventional tillage. Differences in methodologies, diversity of predators, and weed species used may be some explanations for the contrasting results.
Differential survivorship during establishment between large- and small-seeded species is well documented, with large seeds providing an advantage (Moles and Westoby 2004). This benefit occurs primarily while the seedling relies on seed reserves for energy, and once these are depleted, the advantage ends (Lieshman et al. 2000; Dalling and Hubbell 2002; Westoby et al. 2002). A positive relationship was observed between seed size and seedling survival from emergence to one week after emergence; however, no correlation was found between seed weight and plants surviving to maturity (Moles and Westoby 2004). They also reported that in 25 of 31 studies large seeds were advantageous over small seeds under artificially imposed stressful conditions. Bruun and Brink (2008) proposed that large-seeded species have a significant advantage over small-seeded plants when grown in deep shade.

Both Aarssen and Jordan (2001) and Henery and Westoby (2001) reported that as seed weight increased 10-fold, the number of seed produced per plant decreased by the same value. Seed weight is inversely proportional to the number of seeds a plant produces (Moles and Westoby 2004). In a study including pioneer species, Dalling and Hubbell (2002) saw a negative relationship between seed mass and seed abundance in the soil and a positive relationship between seed mass and seedling emergence and survival.

Cropping systems utilizing diverse rotations provide numerous environmental benefits that monocropping systems cannot. Research on diversified systems has shown the benefits include increased nutrient cycling and suppression of pathogens, weeds and insect pests (Drinkwater et al. 1998; Liebman and Dyck 1993; Pimentel et al. 2005). Taking advantage of the benefits diversified systems offer can reduce the amount of synthetic inputs
growers use to replace nature’s cycling processes. This will become especially important as more pressure is put on the agricultural industry to produce goods in an environmentally sustainable way. Attention to long-term, diversified systems must be given to meet future goals of sustainability, profitability, and productivity.

Research Objectives

My main objective was to determine if emergence, growth, and biomass of four weed species differed between a two-year and four-year crop rotation. Within my main objective, we hypothesized that differences in soil characteristics due to crop rotation would negatively affect the survival and growth of small-seeded weed species more than large-seeded species. I also hypothesized that there would be a difference in growth and biomass of weeds emerged at soybean planting compared with those emerged at the soybean second trifoliate growth stage.
WEED GROWTH IN CONVENTIONAL AND LOW-INPUT CROPPING SYSTEMS

A paper to be submitted to *Weed Science*

Rachel B Halbach, Robert G Hartzler, and Matt Liebman

We evaluated the effects of two rotational cropping systems in the soybean year on the growth of common waterhemp, common lambsquarters, giant ragweed, and velvetleaf in Central Iowa. The first experiment evaluated emergence of the four species. Common waterhemp emergence in the two-year system was more than twice that in the four-year system in 2008, whereas giant ragweed emergence was 1.7X greater in the four-year system in 2008. No other differences were observed in cumulative emergence.

A second study evaluated the growth and biomass production of the four weed species when seeds were planted at soybean planting and when soybean was at the V2 stage. Velvetleaf in the first cohort in 2008 exhibited the only mature height difference and was 33 cm shorter in the two-year system compared with the four-year. Mature stem diameter was not influenced by cropping system in any weed species. The first cohort giant ragweed in the two-year system produced only 75% of the biomass of giant ragweed in the four-year system in 2008. First cohort velvetleaf in the two-year system produced 38% of the biomass than that in the four-year in 2008. No difference was detected in giant ragweed or velvetleaf biomass between the systems in 2009 or common waterhemp and common lambsquarters in either year. Height and stem diameter of soybean were greater in the four-year system compared to the two-year. Soybean yield in both years of the study was greater in the four-year system.
**Introduction**

Cropping systems influence weed population dynamics based on the crop species included in the rotation, the cultural and control practices utilized within the rotation, and the environment, along with interactions of the three. Factors such as herbicides used, tillage, planting and harvest dates, and crop competitiveness influence seedbank dynamics, weed growth, fecundity, and mortality. The inclusion of multiple factors that influence weeds makes long-term systems effective at managing weeds with fewer external inputs than less diverse systems (Liebman and Dyck 1993). Because of the wide range of stresses placed on weeds by diverse crop rotations, no single weed species can dominate the system. Conversely, the array of environments allows many different weeds to become established throughout the rotation, contributing to increased diversity (Dorado et al. 1999; Liebman and Dyck 1993). Several studies conducted without herbicides support the idea that diverse systems, compared to conventional systems, result in reduced weed density, but greater weed diversity (Dorado et al. 1999; Liebman and Dyck 1993; Liebman and Staver 2001; Schreiber 1992).

Competitiveness, life cycles, and growth habits of crops used in diversified rotations affect weed dynamics by providing cover for seed predators (Davis and Liebman 2003), introducing allelopathic conditions into the soil (Schreiber 1992), varying planting and harvest timing (Melander et al. 2005; Thurston 1962; Walenta et al. 2002), or altering resource availability (Liebman and Gallandt 1997; Liebman and Staver 2001).

The form of nutrients applied often varies with cropping system and may influence crop and weed growth. When compost was applied to corn and soybean plots, Liebman et al.
(2004) and Menalled et al. (2004) reported increased growth and biomass of common waterhemp compared with plants receiving conventional fertilizer. Menalled et al. (2004) also suggested that compost could alter the male to female plant ratio of common waterhemp as a larger number of male plants were found in composted plots than non-amended plots. Many studies have shown that compost releases phytotoxic chemicals into the soil (Baskin and Baskin 1998; Ligneau and Watt 1995; Marambe and Ando 1992; Ozores-Hampton et al. 1999; Roe et al. 1993) and may change the soil’s water holding capacity, bulk density, and nutrient composition, all of which can influence weed seed germination (Bazzoffi et al. 1998; Gonzalez and Cooperband 2002). Fennimore and Jackson (2003) reported reduced weed emergence in composted plots versus non-composted plots in a vegetable field, whereas Ligneau and Watt (1995) reported that emergence of small-seeded species in a greenhouse was reduced by the addition of compost (large-seeded weeds were not affected).

Moles and Westoby (2004) have reported differential survivorship between large- and small-seeded species, with large seeds being favored. The benefit occurs primarily while the seedling relies on seed reserves for energy, and once used, the advantage ends (Lieshman et al. 2000; Dalling and Hubbell 2002; Westoby et al. 2002). Moles and Westoby (2004) observed a positive relationship between seed size and seedling survival from emergence to one week after emergence; however, they found no correlation between seed weight and plants surviving to maturity. They also reported that under artificially imposed, stressful conditions in 25 of 31 reviewed studies, large seeds had a survival advantage over small seeds. Bruun and Brink (2008) also proposed that large-seeded species have a significant advantage over small-seeded plants when grown in deep shade.
The objective of our research was to determine if emergence, growth, and end-of-season biomass of four weed species differed in the soybean year within a corn-soybean system and a corn-soybean-oat/alfalfa-alfalfa system. We hypothesized that differences in soil characteristics between the two cropping systems would affect the emergence and growth of small-seeded weed species more than large-seeded species. We also hypothesized that there would be a difference in growth and biomass of weeds emerging at soybean planting compared with those emerging at the soybean second trifoliate growth stage.

**Materials and Methods**

**Location and rotational systems**

Weed emergence and growth data were collected in 2008 and 2009 at a field experiment established in 2002 at the Iowa State University Agronomy Farm, located in Boone County, Iowa, USA (42°0’N; 93°6’W). The experiment included three cropping systems and was arranged in a randomized complete block design with each crop of each rotation system present every year in four replicated blocks. Plots measured 18 m by 85 m and soil types at the site included Clarion loam, Nicollet loam, and Webster silty clay loam. The systems were a two-year corn/soybean system, a three-year corn-soybean-small grain/red clover system, and a four-year corn-soybean-small grain/alfalfa-alfalfa system. These systems are typical of Midwest farms with the two-year system similar to a cash grain farm and the three- and four-year systems comparable to integrated crop-livestock farms. Only the two- and four-year systems (CONV and LEI, respectively) in the soybean year were included in the present study.
Management of the two-year system included synthetic fertilizer and herbicide inputs, whereas the three- and four-year rotations included both composted manure and synthetic fertilizers and less reliance on herbicides (for a detailed description of tillage, fertilizer, and herbicide management for each crop in previous years refer to Westerman et al. 2005, Heggenstaller and Liebman 2006, and Liebman et al. 2008). The overall objective of the multi-year experiment is to compare performance of conventional and low-external input cropping systems. However, in order to meet this study’s objectives of comparing weed growth, differences in weed management between systems were eliminated. Each existing soybean plot was split and planted with a glyphosate resistant variety on one half and a non-genetically modified variety on the other. The CONV and LEI cropping system plots planted with glyphosate resistant soybean were included in this study. Management of soybean in both CONV and LEI systems included a glyphosate-resistant variety, Kruger Seeds K-287 RR, planted at 395,200 seeds ha\(^{-1}\) with 76 cm row spacing on 21 May 2008 and 12 May 2009. Fall chisel plow and spring field cultivation were used in both systems. Fall tillage occurred on 6 Nov 2007 and 20 Nov 2008 and spring tillage occurred on 19 May 2008 and 12 May 2009. Glyphosate was applied on 30 June 2008 at 0.84 kg ae ha\(^{-1}\) with 1.2 kg L\(^{-1}\) ammonium sulfate and 17 June 2009 at 0.84 kg ae ha\(^{-1}\). The only fertilizer application to soybean in the two years of this study occurred on 31 Oct 2007 and was a broadcast application of 44 kg ha\(^{-1}\) phosphorus as triple superphosphate and 60 kg ha\(^{-1}\) potassium as potassium chloride as recommended by soil test results. In the year prior to soybean, corn plots in the CONV system received synthetic nitrogen based on soil test results, while LEI
plots received composted manure and reduced rates of synthetic fertilizer. Soybeans were harvested on 6 Oct 2008 and 27 Oct 2009.

Average monthly temperatures and monthly rainfall totals are presented in Table 1. Air temperatures during both growing seasons were consistently below the 30-year mean, with large deviations occurring during April of both years and July and August of 2009. Precipitation in 2008 was characterized by monthly totals well above the mean, while 2009 rainfall was typically below the mean.

**Weed emergence study**

The first study determined the effect of the two cropping systems on emergence of four weed species. After fall tillage in 2007 and 2008, giant ragweed, velvetleaf, common waterhemp, and common lambsquarters were spread on the soil surface in separate 1.5 m by 1.5 m subplots within each plot. Weed seeds were collected during fall 2007 and 2008 from Story County, IA, cleaned, counted, and stored in a dark cooler at 5°C and 50% relative humidity until application in the field. Velvetleaf and giant ragweed were seeded at 1000 seeds m⁻², whereas common waterhemp and common lambsquarters were spread at the rate of 2000 seeds m⁻². Weeds were subject to tillage for seedbed preparation and glyphosate application. Weed emergence and survival were monitored in each subplot beginning 14 April 2008 and 8 April 2009. Weeds present in a 1 m² area in each subplot were counted weekly from the time of first weed emergence until maturity.
Table 1. Thirty-year (1979-2009) mean climate data and 2008 and 2009 deviations from the mean for Boone County, IA.

<table>
<thead>
<tr>
<th>Month</th>
<th>Air temperature (°C)</th>
<th>Precipitation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30-yr mean</td>
<td>2008</td>
</tr>
<tr>
<td>April</td>
<td>10.20</td>
<td>-1.86</td>
</tr>
<tr>
<td>May</td>
<td>16.34</td>
<td>-0.79</td>
</tr>
<tr>
<td>June</td>
<td>21.36</td>
<td>-0.25</td>
</tr>
<tr>
<td>July</td>
<td>23.28</td>
<td>0.05</td>
</tr>
<tr>
<td>August</td>
<td>22.04</td>
<td>-0.93</td>
</tr>
<tr>
<td>September</td>
<td>18.14</td>
<td>-0.36</td>
</tr>
</tbody>
</table>
Weed growth study

A second study was conducted to determine the effect of cropping systems on growth of the four weed species in soybean. The weed seed lots from the previous study were used and stored in a dark cooler at 5°C and 50% relative humidity until planting. Seeds were planted in subplots of the CONV and LEI plots at the time of soybean planting (early) and again when soybean reached the second trifoliate growth stage (late). Seeds were primed for germination before planting. Giant ragweed seed was mixed with damp sand and placed in a dark cooler at 5°C at 50% relative humidity for 8 wk before planting. Two days before planting the mixture was placed in a flat in a greenhouse for 24 h before being moved back into the cooler the day before planting. Velvetleaf seeds were placed in boiling water for 1 min, rinsed with cool tap water, and placed in a refrigerator at 8 degree C for 2 d before planting. Both common waterhemp and common lambsquarters were placed in water 2 d before planting and stored in a refrigerator at 8 degree C.

All seeds were planted 10 cm from the soybean row in a 5 m strip. Giant ragweed was planted approximately 2.5 cm deep and velvetleaf was planted approximately 1.4 cm deep. Common waterhemp and common lambsquarters were mixed with a 2.5 % solution of Laponite RD¹ gel and planted on the soil surface using a syringe. Each subplot was thinned as necessary to 1 plant per 0.5 m for common waterhemp and common lambsquarters and 1 plant per m for giant ragweed and velvetleaf. Four weeks after weeds were planted and each ensuing week until weed maturity (13 and 9 weeks after planting for the first and second

¹ Southern Clay Products, Inc., Gonzales, Texas.
planting, respectively). Plant height and stem diameter were measured for all weeds as well as for 10 randomly chosen soybean plants within each subplot. Height was measured from the soil surface to the apical meristem, and stem diameter was taken directly above the cyledonary scar. Plants were protected from glyphosate application by placing plastic containers over them just before application. As weeds matured shoots were harvested at the soil line, dried at 60° C, and weighed for end-of-season biomass. Velvetleaf capsules were harvested as they matured, while the remaining species were harvested just prior to seed shed. Yields of soybean were determined from 12 weed free rows of each plot using a combine and weigh wagon.

**Statistical analysis**

The emergence study was arranged in a split plot design, replicated over four blocks, with system and year as main plot factors and species as the subplot factor. Data were divided into three time periods corresponding with disturbance events (pre plant - before soybean planting; early season - between planting and glyphosate application; late season - after glyphosate application) and analyzed by species using the GLM procedure of SAS\(^2\) software. The model for each species included block, rotation, year, period, and all interactions between rotation, year, and period. Residual plots were examined for model adequacy. Differences of least squares means were used to determine significances at \(p < 0.05\).

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The weed growth study was arranged in a split plot design, with rotation and year being whole-plot factors and planting time assigned to the subplot with each weed species present in each subplot. Height, stem diameter, and weight values were averaged over plants from the same sub-plot experimental unit. Prior to analyses, model fit was determined by examining residual plots. The model for the three variables included block, rotation, planting time, year, and all interactions, excluding block. Analyses for height and stem diameter were conducted for each week after planting (WAP) by species for the four weed species and soybean grown with each weed. Regression analyses were also conducted on weed and soybean height and stem diameter using SigmaPlot\(^3\). Weed biomass and soybean yield data were analyzed by species. Due to unbalanced data, height, stem diameter, and biomass were not analyzed for common waterhemp at the late planting in either year and common lambsquarters at the late planting in 2008 and both plantings in 2009. Analyses were conducted using Proc Mixed and the residual/restricted maximum likelihood method. Satterthwaite approximation for the denominator degrees of freedom were used and differences in Tukey adjusted least squares means at \( p < 0.05 \) were considered significant.

**Results and Discussion**

**Weed emergence study**

Year and time period within the growing season had a larger effect on emergence of all four weed species than did the cropping system (Table 1 of Appendix A). Emergence of common waterhemp and common lambsquarters was 0.2% or less in both cropping systems in 2009. Differences in emergence between cropping systems within a species were

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\(^3\) SigmaPlot software, version 8.0, 2002, SyStat Software Inc., Point Richmond, CA.
Table 2. Weed seedling emergence from artificial seedbanks as affected by cropping system during 2008 and 2009.\(^{ab}\)

<table>
<thead>
<tr>
<th>Species</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>LEI</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>2.2 a</td>
<td>0.9 b</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>10.9 a</td>
<td>9.1 a</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>3.3 a</td>
<td>1.9 a</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>5.2 a</td>
<td>5.4 a</td>
</tr>
</tbody>
</table>

\(^{a}\) CONV, two-year system; LEI, four-year system.

\(^{b}\) Common waterhemp and common lambsquarters were seeded at a rate of 2000 seeds m\(^{-2}\). Velvetleaf and giant ragweed were seeded at a rate of 1000 seeds m\(^{-2}\). Plots were established in the fall of 2007 and 2008.

\(^{c}\) Values calculated from the mean number of seedlings m\(^{-2}\) of four replicated blocks.

\(^{d}\) Values followed by the same letter within a species and year were not different at \(p < 0.05\).
observed in only two of eight comparisons (Table 2). Emergence of common waterhemp in 2008 and giant ragweed in 2009 was nearly twice as high in the CONV system as in the LEI system. This study showed no consistent effect of cropping system on recruitment of the four weed species from the soil seed bank.

The timing of emergence influences the probability of a weed completing its life cycle. Cropping systems did not affect the emergence patterns of the weeds (Table 1 of Appendix A). Giant ragweed and common lambsquarters are considered early-emerging weeds that have significant emergence prior to and shortly after typical summer annual crop planting dates (Buhler et al. 1997). In both years of this study more than 73% of the giant ragweed emerged prior to planting, whereas over 95% of the common lambsquarters emerged in this time frame (Table 3). Common waterhemp is considered a late-emerging species, and less than 4% of total emergence occurred prior to planting. No differences in velvetleaf emergence occurred among the three sampling periods in 2008, whereas in 2009 emergence of velvetleaf prior to soybean planting was nearly twice that observed in either of the later sampling periods.

While our study did not establish that one system was more favorable for weed establishment than the other, previous studies have reported emergence differences among cropping systems. For example, compost is typically used in diverse cropping systems as fertilizer and to increase organic matter. Fennimore and Jackson (2003) explained reduced weed emergence in composted plots versus non-composted plots due to a negative correlation between microbial biomass and weed emergence. In a greenhouse study, Ligneau and Watt (1995) found that emergence of small-seeded species was reduced by the addition
Table 3. Emergence patterns of four weed species from artificial seedbanks in 2008 and 2009.$^{ab}$

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th></th>
<th>2009</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Plant</td>
<td>Early Season</td>
<td>Late Season</td>
<td>Pre Plant</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>3.6 a$^d$</td>
<td>91.9 b</td>
<td>4.4 a$^e$</td>
<td>-</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>95.1 a</td>
<td>4.4 b</td>
<td>0.4 b</td>
<td>-</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>26.6 a</td>
<td>56.0 a</td>
<td>17.4 a</td>
<td>49.2 a</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>82.6 a</td>
<td>9.9 b</td>
<td>7.5 b</td>
<td>73.3 a</td>
</tr>
</tbody>
</table>

$^a$Pre plant- time before spring tillage; early season- time between tillage and glyphosate application; late season- time after glyphosate application.

$^b$Common waterhemp and common lambsquarters were seeded at a rate of 2000 seeds m$^{-2}$. Velvetleaf and giant ragweed were seeded at a rate of 1000 seeds m$^{-2}$. Plots were established in the fall of 2007 and 2008.

$^c$Values calculated from the mean number of seedlings emerged m$^{-2}$ from four replications, pooled over two- and four-year cropping systems.

$^d$Percentages followed by the same letter within a species and year were considered not different at $p < 0.05$.

$^e$Dashes represent data not presented due to low emergence.
of compost. LEI plots in our study received composted manure after the alfalfa year, so its effects may have been lost by the soybean year. Another practice typical of long-term systems is the incorporation of cover crops, which can increase populations of fungi and other soil pathogens (Dabney et al. 1996; Kirkpatrick and Rothrock 1995). Fungi negatively affected emergence of corn chamomile (*Anthemis arvensis*) seeds compared with fungicide-treated seeds in soil incorporated with fresh buckwheat residue (Kumar et al. 2008). Again, effects of this practice may have been diminished in our LEI system, as alfalfa preceded corn in the LEI system.

**Weed growth study**

Due to poor emergence and survival, common lambsquarters data for early planting 2008 and late planting 2008 and 2009 are not presented. Late planting common waterhemp data for both years are also not presented for the same reason.

Velvetleaf was the only weed species to differ in height at maturity between cropping systems (Table 4). Velvetleaf was 33 cm taller in the LEI system than the CONV at maturity in 2008. No differences in velvetleaf height were observed prior to the final measurements (13 WAP). When plant height was compared between planting times over years among plants the same age, velvetleaf in the late planting was taller at 4, 5, and 6 WAP (data not shown) compared to the early planting. No height difference was found at 7 WAP, but in the following two weeks plants in the first cohort were taller than those in the second. At maturity (9 WAP), the late planted velvetleaf were 54 cm shorter than those in the first cohort at the same age. The increased height early in the season of late planted velvetleaf may be due to the shade avoidance response (Smith 1982).
Table 4. Mature height of four weed species as affected by cropping system and planting date.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Species</th>
<th>2008 CONV</th>
<th>2008 LEI</th>
<th>2009 CONV</th>
<th>2009 LEI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common waterhemp</td>
<td>162 (8)</td>
<td>185 (11)</td>
<td>149 (14)</td>
<td>165 (14)</td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>136 (7)</td>
<td>148 (9)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>128* (11)</td>
<td>161* (13)</td>
<td>136 (11)</td>
<td>132 (16)</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>182 (8)</td>
<td>197 (10)</td>
<td>196 (8)</td>
<td>190 (8)</td>
</tr>
<tr>
<td>Late planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>23 (5)</td>
<td>38 (5)</td>
<td>17 (5)</td>
<td>11 (5)</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>67 (10)</td>
<td>91 (12)</td>
<td>103 (10)</td>
<td>98 (22)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Early, planted at soybean planting; Late, planted at soybean second trifoliate growth stage; CONV, two-year system; LEI, four-year system. Maturity for Early was 13 weeks after planting and 9 weeks after planting for Late.

\textsuperscript{b}Values are pooled over four replications. Values in parentheses are standard errors of the mean.

\textsuperscript{c}Dashes represent parameters where data were not presented.

\textsuperscript{*}Asterisks represent values that were different within a species, planting, and year at Tukey adjusted $p < 0.05$. 
While mature giant ragweed did not differ in height between systems, it did have a response to planting time similar to velvetleaf. At 5, 6, and 7 WAP, the second cohort plants were taller than those in the first, but unlike velvetleaf, height of giant ragweed at the early planting didn’t exceed that of the late planted giant ragweed later in the season. Averaged over years at 9 WAP, plants were 90 cm tall at both plantings.

No factors in our models were shown to influence height of common waterhemp and common lambsquarters. Equations for predicted height values of all weed species are shown in Table 1 of Appendix B.

Cropping system did not affect mature weed stem diameter (Table 5). Larger stems in LEI than CONV were observed at 4 and 5 WAP for early planted common waterhemp and 8 WAP for early planted velvetleaf in 2008 (data not presented). Differences for common waterhemp were 0.3 mm at 4 WAP and 1.1 mm at 5 WAP. Velvetleaf had a difference of 3.3 mm at 8 WAP.

Stem diameter of velvetleaf and giant ragweed were affected by planting date both years. Differences occurred at 7 and 9 WAP favoring velvetleaf in the first cohort by 3.4 and 6.4 mm, respectively, while stem diameter of giant ragweed was greater at 6, 7, 8, and 9 WAP in the first planting. Equations for predicted stem diameter values for each species are presented in Table 2 of Appendix B.

Biomass of the early planting of common waterhemp in both years and common lambsquarters in 2008 was not affected by any factor included in our models. Cropping system significantly affected early planting velvetleaf biomass in 2008. Velvetleaf grown in the CONV system produced 133.4 grams (62%) less biomass than those in the LEI (Table 6).
Table 5. Stem diameter of four weed species as affected by cropping system and planting date.\(^a\)

<table>
<thead>
<tr>
<th>Species</th>
<th>2008</th>
<th>2009</th>
<th></th>
<th>2008</th>
<th>2009</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>LEI</td>
<td></td>
<td>CONV</td>
<td>LEI</td>
<td></td>
</tr>
<tr>
<td>Early planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common waterhemp</td>
<td>16.1 (2.9)</td>
<td>17.8 (3.7)</td>
<td>15.0 (2.1)</td>
<td>15.9 (2.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>9.6 (1.0)</td>
<td>7.6 (1.3)</td>
<td></td>
<td>7.6 (1.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>9.0 (2.5)</td>
<td>16.6 (3.2)</td>
<td>12.0 (2.1)</td>
<td>16.3 (3.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>23.7 (6.5)</td>
<td>37.9 (8.4)</td>
<td>26.6 (17.1)</td>
<td>29.6 (12.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>4.3 (0.8)</td>
<td>6.7 (0.9)</td>
<td>3.5 (1.0)</td>
<td>3.3 (0.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>3.9 (2.2)</td>
<td>8.8 (2.6)</td>
<td>3.8 (3.4)</td>
<td>6.8 (3.5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Early, planted at soybean planting; Late, planted at soybean second trifoliate growth stage; CONV, two-year system; LEI, four-year system. Maturity for Early was 13 weeks after planting and 9 weeks after planting for late.

\(^b\) Values are pooled over four replications. Values in parentheses are standard errors of the mean. No differences within a planting and year were observed at Tukey adjusted \(p < 0.05\).

\(^c\) Dashes represent parameters where data were not presented.
Table 6. Mature plant biomass of four weed species as affected by cropping system and planting date.\(^{'a}\)

<table>
<thead>
<tr>
<th>Species</th>
<th>2008</th>
<th>2009</th>
<th></th>
<th>2008</th>
<th>2009</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>LEI</td>
<td>CONV</td>
<td>LEI</td>
<td>CONV</td>
<td>LEI</td>
</tr>
<tr>
<td>Early planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>90.8 (a) (51.3)</td>
<td>143.5 (a) (51.3)</td>
<td>99.1 (a) (60.5)</td>
<td>76.6 (a) (60.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>65.4 (a) (17.1)</td>
<td>63.5 (a) (17.1)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>82.2 (a) (12.3)</td>
<td>215.6 (b) (14.2)</td>
<td>52.8 (a) (12.3)</td>
<td>53.8 (a) (17.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>538.0 (a) (32.4)</td>
<td>714.0 (b) (32.4)</td>
<td>781.2 (a) (32.4)</td>
<td>772.8 (a) (32.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
<td>-(^d)</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>54.9 (a) (14.2)</td>
<td>65.1 (a) (14.2)</td>
<td>1.1 (a) (12.3)</td>
<td>0.6 (a) (14.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>24.3 (a) (32.4)</td>
<td>311.1 (b) (67.9)</td>
<td>26.0 (a) (32.4)</td>
<td>2.0 (a) (38.0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{'a}\) Early, planted at soybean planting; Late, planted at soybean second trifoliate growth stage; CONV, two-year system; LEI, four-year system. Maturity for Early was 13 weeks after planting and 9 weeks after planting for Late.

\(^{b}\) Values are means pooled over four replicated blocks. Values in parentheses are standard errors of the mean.

\(^{c}\) Values followed by the same letter within a planting and year were not considered different at Tukey adjusted \(p < 0.05\).

\(^{d}\) Dashes represent parameters where data were not presented.
No difference was detected in 2009. There was also no difference in biomass when 2008 and 2009 were compared in the CONV system; however, plants in the LEI in 2008 totaled 161.8 g more than those in 2009.

Okalebo et al. (2008) documented velvetleaf suppressive soil and hypothesized that pathogens such as *Rhizoctonia solani*, *Pythium* and *Fusarium* species were responsible for high mortality and reduced growth. To determine if the LEI system was a suppressive soil, extra plots of velvetleaf were planted in both systems in 2009 and monitored for disease; however, no disease was detected.

Planting time influenced velvetleaf biomass, with early planted velvetleaf producing 85.9 g more in 2008 and 52.5 g more in 2009 than those planted at the soybean second trifoliate leaf stage. No difference was detected between systems or years in the second cohort.

Giant ragweed biomass was affected by system at both plantings in 2008. The LEI system produced 176.0 g more in the early planting and 287.8 g more in the late planting. No difference was detected in 2009. Planting date was significant in 2008 and 2009. The first planting out-yielded the second by 458.3 g in 2008 and 763.0 g in 2009. Biomass production was significant between years in the LEI system. Although no block effect was detected, larger plants in the fourth replication (compared to other replications) were observed where topsoil had washed into in 2008. We speculate that this is the cause of the more than 150-fold difference.
Table 7. Mature height and stem diameter of soybean grown in a two- or four-year cropping system in competition with four weed species.\textsuperscript{ab}

<table>
<thead>
<tr>
<th>Soybean grown with</th>
<th>Height</th>
<th>Stem diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>LEI</td>
</tr>
<tr>
<td></td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>87 a</td>
<td>99 b</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>97 a</td>
<td>97 a</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>90 a</td>
<td>99 b</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>91 a</td>
<td>94 b</td>
</tr>
</tbody>
</table>

\textsuperscript{a} CONV, two-year system; LEI, four-year system.

\textsuperscript{b} Plants were considered mature at 13 weeks after planting.

\textsuperscript{c} Values are means of four replicated blocks pooled over year and weeds planted at soybean planting and at soybean second trifoliate leaf stage.

\textsuperscript{d} Values followed by the same letter within a species and parameter were not considered significant at Tukey adjusted $p < 0.05$. 
Soybean growth and yield

Soybean height was affected by cropping system when grown in competition with common waterhemp, velvetleaf, and giant ragweed (Table 7). Mature height of LEI soybean was 12, 9 and 3 cm taller than CONV soybean when grown with common waterhemp, velvetleaf, and giant ragweed, respectively. Height of soybean grown with common lambsquarters was not different between systems. Equations for predicted height values are shown in Table 3 of Appendix B.

When common waterhemp and common lambsquarters were grown with soybean, mature stem diameter of the crop was greater in the LEI system by 0.5 and 0.7 mm, respectively (Table 7). For soybean grown with common lambsquarters this was the only observed difference, but when grown with common waterhemp, the difference also occurred at 11 and 12 WAP. Soybean planted with giant ragweed differed in stem diameter at 7, 8, and 9 WAP, again favoring the LEI system. No difference between systems was observed for soybean grown with velvetleaf. Equations for predicted stem diameter values for each species grown with soybean are located in Table 4 of Appendix B.

During the two years of our study, weed free soybean yield of the glyphosate tolerant variety was not different between systems, but yield of the conventional variety did differ between systems (Table 8). When pooled over variety, yield was again significant, favoring the LEI system by 504.4 kg ha$^{-1}$ in 2008 and 544.6 kg ha$^{-1}$ in 2009 (data not shown). Since
Table 8. Weed free yield of two soybean varieties as affected by cropping system.\textsuperscript{ab}

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K-287 RR</td>
<td>K-2918</td>
<td>K-287 RR</td>
<td>K-2918</td>
</tr>
<tr>
<td>CONV</td>
<td>3581 A a</td>
<td>3294 A a</td>
<td>3535 A a</td>
<td>3221 A a</td>
</tr>
<tr>
<td>LEI</td>
<td>3915 A a</td>
<td>3955 B a</td>
<td>4015 A a</td>
<td>3815 B a</td>
</tr>
</tbody>
</table>

\textsuperscript{a} CONV, two-year system; LEI, four-year system.

\textsuperscript{b} Yield was adjusted to 13 \% moisture and pooled over four replications.

\textsuperscript{c} Yields followed by the same capitalized letter within a year and variety were not different at \( p < 0.05 \). Yields followed by the same lowercase letter within a year and system were not different at \( p < 0.05 \).
the establishment of the ongoing cropping systems study, soybean grown in the LEI system 
has out-yielded the CONV five of eight times.

In a recent study, weed biomass was four to seven times greater in an organic system 
compared to a conventional system (Ryan et al. 2010). However, corn in the organic system 
was more tolerant of weed competition than in the conventional system. Another study 
reported that soybean yields in long-term systems exceeded those in conventional systems 
(Mallarino et al. 2006). McAndrews et al. (2006) observed weed free soybean plots that 
were amended with compost one and one half years prior to planting. They found taller 
plants with larger stem diameters that yielded more that plants in urea-amended plots. We 
observed taller soybean plants with greater stem diameters and higher yields in the LEI 
system, supporting that under competition soybean is more productive in low-external input 
systems.

Similar to the emergence study, our growth study results did not show a strong 
cropping system effect on the growth of weeds. In addition to affecting emergence, use of 
compost can alter height, biomass, and seed production. Liebman et al. (2004) reported that 
increased soil phosphorus and potassium concentrations, as a result of compost application, 
enhanced height, biomass, and seed production of common waterhemp and velvetleaf 
compared to those grown in plots managed with conventional fertilizer. Another study by 
Menalled et al. (2004) found similar results when compost was applied to field plots. They 
observed an increase in common waterhemp height, stem diameter, and biomass over control 
plots. Compost applications in earlier studies occurred in the fall prior to emergence 
measurements, while amendments to LEI plots in our study occurred in the fall prior to corn
planting (approximately one and one half years before soybean planting). Effects of compost on weed height, stem diameter, and biomass may have been negligible due to the extended time since application.

Large standard deviations for height, stem diameter, and biomass production means were typical for plants of the same species within a plot. For example, the difference between the average minimum and maximum height of velvetleaf in the CONV system in 2008 at the early planting was 31 cm. The variability was not consistently greater in one system compared with the other. Differences in the measured parameters may not have been detected due to this variability.

Our hypotheses relating to differential emergence, growth, and biomass between cropping systems and weed seed size were not strongly supported by our observations. In the two of eight comparisons where cumulative emergence varied between systems, greater emergence was observed in the CONV than the LEI system and involved a small and large seeded species. Weed biomass was greater in the LEI than CONV system in three out of eleven comparisons. We had speculated that the small seeded species would be more responsive to changes in soil quality between the systems, but the differences in biomass were observed in velvetleaf and giant ragweed, the two large-seeded species. Plant growth is influenced by interactions among the plant, soil conditions, environment, and other organisms. A possible explanation for the observed results is that growth of both crops and weeds were favored in the LEI system. The small seeded species may not have benefited from the more favorable conditions due to increased competition from the crop. The more rapid establishment and greater stress tolerance of the large seeded species may have allowed
them to overcome the increased soybean growth. Comparing growth rates of weeds in both systems with and without competition would allow testing of this hypothesis. Based on these studies, changes in soil quality among the two cropping systems appeared to have a relatively small effect on weed growth compared to the other factors.

**Literature Cited**


GENERAL CONCLUSIONS

Two studies were conducted to determine if weed emergence and growth within soybean differs between conventional and low-input cropping systems. Many published studies show that plant emergence and growth are affected by crop species, tillage, cover cropping, composting, and harvest timing. All of these factors can be components of diversified systems, and practices within these systems are thought to create a healthier soil. We hypothesized that differences in soil of the two systems would affect emergence and growth of four weeds differently, with smaller seeds being more sensitive to those changes.

The study focusing on emergence found only two differences between systems among eight comparisons in the number of seedlings emerging. Common waterhemp in 2008 and giant ragweed in 2009 both had more seedlings emerge in the conventional system. Timing of weed emergence was not affected by cropping system. The weed growth study analyzed the growth of four weeds over the course of the season. Height and stem diameter were generally affected only by planting time and year. The only height difference between cropping systems was observed in velvetleaf, with taller plants found in the long-term system in 2008. Also in 2008, common waterhemp stem diameter was larger in the four-year system at 4 and 5 weeks after planting, while velvetleaf was larger only at 8 weeks after planting. End of season biomass of common waterhemp and common lambsquarters was not affected by cropping system, but the large-seeded species produced more when grown in the diversified system in 2008 at the early planting. Soybean grown in competition with the weeds generally were taller and had larger stems in the long-term system. Over the course of the long-term study of which this research was a part, soybean yields in the low-external input system have been larger in than the conventional system five of eight years.
Few differences between systems were found, but published literature has provided evidence of diversified systems being more suitable for plant growth and production. Soil quality, environmental conditions and other organisms influence seed germination and plant growth; however, in these studies differences in soil quality between conventional and diversified systems had a small effect compared with other factors and interactions.
LITERATURE CITED


ACKNOWLEDGEMENTS

This research project would not have been possible without the support of many people. I am grateful for Dr. Bob Hartzler, who throughout my program pushed me to think deeper and provided invaluable knowledge and guidance. Without his direction and help this research would not have made it to fruition. I also thank my committee members, Dr. Matt Liebman and Dr. Thomas Jurik, for their time, feedback, and advice.

I appreciate the help of Nick Siepker and Kristine Kohlhaas, who collected data with me in mud, wind, and other less than ideal conditions. Their camaraderie made light of the tasks.

I have been blessed with a wonderful support system of family and friends who have been a continuing source of support and encouragement. I especially thank my husband, Phil, for his love and patience, my parents, Steve and Amy, for their confidence in me, and Heather Hall for her ability to make any situation laughable.
APPENDIX A

Table 1. Results of statistical tests of effects on the seedling emergence in four weed species during 2008 and 2009.\(^a\)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Common Waterhemp</th>
<th>Common Lambsquarters</th>
<th>Velvetleaf</th>
<th>Giant Ragweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>0.0726</td>
<td>0.1220</td>
<td>0.1535</td>
<td>0.5748</td>
</tr>
<tr>
<td>System</td>
<td>0.0141</td>
<td>0.2611</td>
<td>0.4001</td>
<td>0.0040</td>
</tr>
<tr>
<td>Year</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>System*Year</td>
<td>0.0054</td>
<td>0.4833</td>
<td>0.7925</td>
<td>0.0024</td>
</tr>
<tr>
<td>Period</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0167</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>System*Period</td>
<td>0.0339</td>
<td>0.2728</td>
<td>0.0588</td>
<td>0.0715</td>
</tr>
<tr>
<td>Year*Period</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0028</td>
<td>0.0019</td>
</tr>
<tr>
<td>System<em>Year</em>Period</td>
<td>0.0094</td>
<td>0.7554</td>
<td>0.2754</td>
<td>0.0922</td>
</tr>
</tbody>
</table>

\(^a\)Weeds were planting in a two- or four-year cropping system replicated in four blocks.

Each year was broken into three periods: prior to soybean planting, early season (after planting, before glyphosate application), and late season (after glyphosate application).

\(^b\)P-values were considered significant at < 0.05.
### APPENDIX B

**Table 1.** Equations for predicted height values (in cm) at given weeks after planting of four weed species.\(^{ab}\)

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Planting Date</th>
<th>System</th>
<th>Equation</th>
<th>R Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Lambsquarters</td>
<td>2008</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = 18.28 - 11.06x + 1.61x^2)</td>
<td>0.92</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>2008</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = 8.54 - 9.77x + 1.77x^2)</td>
<td>0.91</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>2009</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-127.70) + 26.75x - 0.46x^2)</td>
<td>0.86</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>2008</td>
<td>Early</td>
<td>CONV</td>
<td>(y = 14.60 - 9.24x + 1.43x^2)</td>
<td>0.93</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>2008</td>
<td>Early</td>
<td>LEI</td>
<td>(y = 25.02 - 13.49x + 1.93x^2)</td>
<td>0.96</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>2008</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = (-16.90) + 7.03x - 0.16x^2)</td>
<td>0.21</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>2009</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-91.55) + 18.77x - 0.19x^2)</td>
<td>0.86</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>2009</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = (-1.36) + 2.86x - 0.12x^2)</td>
<td>0.26</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2008</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-7.95) - 3.15x + 1.32x^2)</td>
<td>0.96</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2008</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = (-13.37) + 2.52x + 0.95x^2)</td>
<td>0.43</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2009</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-150.50) + 35.98x - 0.79x^2)</td>
<td>0.94</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2009</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = (-31.60) + 15.41x - 0.17x^2)</td>
<td>0.64</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: Early, planted at soybean planting; Late, planted at soybean Late trifoliate growth stage; CONV, two-year system; LEI, four-year system.

\(^b\) If no statistical difference between systems was observed, values were pooled.
Table 2. Equations for predicted stem diameter (in mm) at given weeks after planting of four weed species.\textsuperscript{ab}

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Planting Time\textsuperscript{a}</th>
<th>System\textsuperscript{b}</th>
<th>Equation</th>
<th>R Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Lambsquarters</td>
<td>2008</td>
<td>Early</td>
<td>Pooled\textsuperscript{c}</td>
<td>(y = (-3.0) + 0.82x + 0.01x^2)</td>
<td>0.72</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>2008</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-10.40) + 2.67x - 0.03x^2)</td>
<td>0.66</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>2009</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-19.48) + 5.19x - 0.20x^2)</td>
<td>0.74</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Pooled</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-5.26) + 1.44x + 0.00x^2)</td>
<td>0.64</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Pooled</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = 0.32 + 0.17x + 0.01x^2)</td>
<td>0.15</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2008</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-7.78) + 2.06x + 0.06x^2)</td>
<td>0.78</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2008</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = 0.10 + 0.31x + 0.06x^2)</td>
<td>0.18</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2009</td>
<td>Early</td>
<td>Pooled</td>
<td>(y = (-24.26) + 7.51x - 0.30x^2)</td>
<td>0.80</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2009</td>
<td>Late</td>
<td>Pooled</td>
<td>(y = 1.06 + 0.18x + 0.03x^2)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Abbreviations: Early, planted at soybean planting; Late, planted at soybean Late trifoliate growth stage; CONV, two-year system; LEI, four-year system.

\textsuperscript{b}If no statistical difference between systems or years was observed, values were pooled.
Table 3. Equations for predicting soybean height (in cm) when grown in competition with four weeds at given weeks after planting.\(^ab\)

<table>
<thead>
<tr>
<th>Soybean grown with</th>
<th>Year</th>
<th>System</th>
<th>Equation</th>
<th>R Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Waterhemp</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-19.62) + 4.7x + 0.29x^2)</td>
<td>0.95</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-25.70) + 6.30x + 0.26x^2)</td>
<td>0.96</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>2008</td>
<td>Pooled</td>
<td>(y = (-17.53) + 4.23x + 0.36x^2)</td>
<td>0.95</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-38.44) + 9.40x + 0.03x^2)</td>
<td>0.95</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-41.27) + 10.36x - 0.03x^2)</td>
<td>0.94</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-38.44) + 0.67x + 0.01x^2)</td>
<td>0.94</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-41.42) + 10.38x + 0.01x^2)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

\(^a\)Abbreviations: CONV, two-year system; LEI, four-year system.

\(^b\)Common waterhemp and common lambsquarters were planted at a rate of 10 plants m\(^2\) soybean row.

Velvetleaf and giant ragweed were planted at a rate of 5 plants m\(^2\) soybean row. If no statistical difference between systems or years was observed, values were pooled.
Table 4. Equations for predicting soybean stem diameter (in mm) when grown in competition with four weed species at given weeks after planting in 2008 and 2009.\(^{ab}\)

<table>
<thead>
<tr>
<th>Soybean grown with</th>
<th>Year</th>
<th>System</th>
<th>Equation</th>
<th>R Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Waterhemp</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-0.48) + 0.73x - 0.02x^2)</td>
<td>0.69</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-0.90) + 0.86x - 0.02x^2)</td>
<td>0.71</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-0.75) + 0.83x - 0.03x^2)</td>
<td>0.69</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-0.56) + 0.74x - 0.02x^2)</td>
<td>0.73</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Pooled</td>
<td>Pooled</td>
<td>(y = (-1.22) + 0.92x - 0.03x^2)</td>
<td>0.71</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Pooled</td>
<td>CONV</td>
<td>(y = (-0.71) + 0.77x - 0.02x^2)</td>
<td>0.70</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Pooled</td>
<td>LEI</td>
<td>(y = (-1.20) + 0.95x - 0.03x^2)</td>
<td>0.68</td>
</tr>
</tbody>
</table>

\(^{a}\) Abbreviations: CONV, two-year system; LEI, four-year system.

\(^{b}\) Common waterhemp and common lambsquarters were planted at a rate of 10 plants m\(^{-2}\) soybean row. Velvetleaf and giant ragweed were planted at a rate of 5 plants m\(^{-2}\) soybean row. If no statistical difference between systems or years was observed, values were pooled.