Factors influencing weed spatial distribution

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Factors influencing weed spatial distribution

by

Bruce Allen Battles

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Major: Crop Production and Physiology
Major Professor: Robert G Hartzler

Iowa State University
Ames, Iowa
2001
This is to certify that the Master's thesis of

Bruce Allen Battles

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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LITERATURE REVIEW

Weed spatial patterns commonly occur as patchy patterns within agricultural fields. These patterns may be associated with soil characteristics, such as water drainage, pH and nutrient availability, or with past or current management practices such as sprayer skips and weed seed movement. In most situations it is difficult to determine what factors are responsible for the pattern of weed distribution. Many studies have associated a single soil characteristic with germination, growth and seed production of weed species, but few have evaluated the interaction of multiple soil characteristics on weed dynamics.

Spatial distribution of weeds

Spatial distributions of weeds are highly variable between and within agricultural fields. Dependent largely upon previous management practices and variation of soil and environmental properties, weed distributions can range from large areas with uniform densities to small patchy distributions. Spatial patterns of weeds are generally similar to seed bank distributions. Cardina et al. (1996) observed high correlations between common lambsquarter emergence and seed bank densities in no-till and moldboard plow tillage systems. Areas were also observed where seed banks were poorly correlated with weed densities. Although weed densities and seed banks are generally correlated, few studies have adequately explained the spatial variability of weeds that is commonly observed.

Soils have a wide range of characteristics that are non-uniformly distributed in fields (Cambardeilla et al., 1994; Gajem et al., 1981; Lascaro et al., 1992). Suddeth
et al. (1994) reported highly variable water holding capacity, soil nutrients, soil pH, top soil depth, crop growth, and yield within fields located in claypan areas. Numerous studies have cited relationships between weed species and soil characteristics (Buchanan et al., 1975; Salas et al., 1997; Weaver and Hamill, 1985). Many of these studies showed increased growth and fecundity of weeds in response to elevated nutrient levels.

Highly variable soil characteristics could also increase weed spatial patterns and densities indirectly via effects on herbicide efficacy. Ghidey et al. (1997) observed increased concentrations of uniformly applied atrazine and alachlor in areas where soil pH was lower as well as where organic matter content and cation exchange capacity were higher. Many others have also found herbicide availability to be related to soil properties such as organic matter content and soil pH (Best et al., 1975; Best and Weber, 1974; Corbin et al., 1971; Kells et al., 1980; Sheets, 1970; Weber, 1970). Kozak et al. (1992) found clay content, carbon content, pH (KCL) and CEC value to be most appropriate for estimation and prediction of herbicide adsorption. In areas with high sorption, soil-applied herbicides are more likely to be adsorbed by soil particles and organic matter than be dissolved into soil solution, therefore making them less available for plant uptake (Blackshaw et al., 1994; Blumhorst et al., 1990).

**Factors influencing spatial dynamics**

**Seed bank**

Weeds are persistent in the environment and the majority of species found
within arable fields are annuals that depend upon seed production to regenerate future populations. Soil acts as a storage area for seeds and is commonly referred to as the soil seed bank. The soil seed bank represents viable weed seeds stored within the soil that could germinate under favorable conditions. Characteristics of seed banks within the soil undoubtedly influence weed densities and distributions. Rothrock et al. (1993) found high correlations ($r>0.95$) between weed density and seed bank size. Variability of soil characteristics and management practices may influence the likelihood of weed survival and seed production and thus influence seed bank size and distribution. The highly variable seed bank characteristics are undoubtedly one of the most important forces influencing weed populations, thus understanding the mechanisms that drive it are important for the development of weed control strategies.

**Seed bank size**

The density of the soil seed bank can be highly variable, ranging anywhere from zero to several hundred thousand seeds per square meter. In some early work done by Robinson (1949), seed banks were found to range from 900 to 43,000 seeds per square meter. More recently, Forcella et al. (1992) found seed banks in the United States corn belt ranging from 600 to 162,000 seeds per square meter. While the seed bank has the potential of being large, usually only a small percentage of the viable seed will emerge. Barralis et al. (1996) estimated an average seedbank of 2864 seeds per square meter, but only 6% of viable seeds germinated. Zhang et al. (1998) found germination rates of 3 to 7% of viable seeds.
Percent emergence is generally low in weeds although it is highly dependent upon species. In studies by Barralis et al. (1996), percent emergence ranged from 1% with fluvellins (*Kickxia spuria*) to 33% for lady's thumb (*Polygonum persicaria*). In studies by Perez et al. (1998), common lambsquarters (*Chenopodium album*) and annual erigonum (*Erigonum annuum*) had some of the largest seed banks but germination was less than 6%.

Variability in weed seed production also contributes to heterogeneous spatial patterns. Factors such as soil moisture and interspecific competition are quite variable across fields and can enhance or suppress plant seed production. Weeds typically emerge at various times throughout the growing season, with later emerging weeds producing less seed (Cardina et al., 1995).

Effective weed management can decrease seed bank densities, however seed producing plants escaping control practices can rapidly increase seed banks (Buhler et al., 1997). Common waterhemp (*Amaranthus rudis*) growing under optimum conditions have been found to produce over two million seeds per plant (Battles et al., 1998), resulting in a quick replenishment of the seed bank. Each year of weed control is important to the size of following seed banks and control efficacy. Hartzler and Roth (1993) observed a 20% increase in giant foxtail (*Setaria faberi*) control when the previous year's weed control was maintained at 100% as compared to 70%. As the density of weed seedlings increases, the number of seedlings that survive will also increase (Dieleman et al. 1999).

Crop production practices such as tillage also influence weed seed bank size.
In studies observing seed bank responses to tillage, Ball (1992) found over a three year period that seed bank size increased more rapidly in chisel plowed treatments than when moldboard plowed. When herbicides were used to control weeds, a more rapid decline of seed banks was seen in moldboard rather than chisel plowed plots.

Predation of seed banks by vertebrate and invertebrate animals can sometimes lead to significant decreases in seed densities. Seed losses due to predation can be as high as 70% in a natural system (Crawley, 1992). Although not as great as in natural systems, seed predation does occur in agricultural fields. Brust and House (1988) reported weed seed losses in no till soybeans due to predation as high as 69%. However, under conventional tillage systems, seed losses reached only 27%. Higher weed seed losses in no till systems were attributed to the quantity of seed remaining on the soil surface that was more accessible to predators. Seed bank decline within conventional tillage systems are most likely due to invertebrate predation (Brust and House, 1988), although significant seed losses due to infection by fungi and other microorganisms are also common (Kremer 1993).

**Tillage**

Tillage influences spatial and temporal distribution of seed banks. Patterns of weed distribution have been correlated with the direction of implement traffic (Mortensen and Dieleman, 1997). Vertical distribution of weed seeds in the soil by tillage equipment has a large influence on seed bank environment and the potential for germination. Tillage can bury seed within the soil causing a dilution effect,
making horizontal patchiness less discrete (Cardina et al., 1996). Seedling recruitment depths of most weed species are typically shallower within no-till than conventional tillage fields (du Croix Sissons et al., 2000). Differences in emergence patterns (temporal and spatial distribution) can be seen when comparing conventional and no tillage systems. Seeds are distributed horizontally as well as vertically in space within a conventional tillage system as compared to no till operations in which horizontal distribution is the dominant displacement pattern. The lack of vertical distribution in no till systems creates a spatial pattern where patchiness is more prevalent than in conventional tillage systems (Cardina et al.1996).

Since tillage systems have a large impact on distribution of seeds within the soil profile, weed spatial patterns are largely dependent upon the depth in which species are able to recruit emergence. Wild oat (Avena fatua) has been documented to emerge from as deep as 20 cm while germination at shallower depth is inhibited due to dormancy induced by light (Sharma and Vanden Born, 1978). Dawson and Bruns (1962) observed highest levels of yellow foxtail (Setaria glauca), barnyardgrass (Echinochloa crusgalli), and green foxtail (Setaria viridis) emergence from depths of 1.3 to 2.5 cm below soil surface; although emergence tended to decrease with seed planting depth.

**Microsites**

Heterogeneity of soils creates a variety of microsites with unique moisture and aeration conditions that could influence seed germination and seedling
establishment (Evans and Young, 1972; Evans and Young, 1972; Harper and Benton, 1966; Harper et al., 1965). Several researchers have observed correlations between soil microsite characteristics and germination of seeds (Currie, 1961; Pareja et al., 1985; Pareja and Staniforth, 1985; Spitters, 1989; Terpstra, 1986). Size of soil aggregates dictate the microsite habitat that surrounds seeds. Pareja et al. (1985) reported that conventional tillage uniformly incorporated weed seeds into many soil aggregate classes, whereas reduced tillage systems accumulated more seed in the unaggregated portion of the soil. Generally as the diameter of the soil clod surrounding the seed increases, germination can be decreased by as much as 23 percent (Terpstra, 1986). The increasing diameter of a soil clod may act as a barrier to oxygen needed for germination (Benvenuti and Macchia, 1995; Smith, 1977; Stabell et al., 1998).

**Dormancy**

Emergence of common annual weed species can range anywhere from 1 to 50% (Cousens and Mortimer 1995; Forcella et al. 1992; Roberts and Ricketts 1979; Wilson and Lawson 1992); while three to six percent emergence is most commonly reported. The large number of seed not emerging was usually a result of dormancy. Seed dormancy is one attribute which prevents the eradication of most weeds and also defines many plants as a weed. Villers (1972) defined seed dormancy as: "the state of arrested development whereby the organ or organism, by virtue of its structure or chemical composition, may possess one or more mechanisms preventing its own germination". The mechanisms that prevent the germination of
seeds allow germination to be delayed to another point in time. Randomness of seed germination due to different dormancy levels can account for highly variable spatial patterns that develop in fields and explain why we have been unsuccessful at eradicating weed species through the use of management practices such as tillage and herbicides. Dormancy of seeds can be categorized as either primary or secondary dormancy. Copeland and McDonald (1985) defined primary dormancy as the state in which seeds will not germinate under conditions that would normally be favorable for germination, at the time of or shortly after seed dispersal. Secondary dormancy was defined as nondormant seed which become dormant after exposure to unfavorable conditions. Taylerson (1986) observed that hydrated, nondormant giant foxtail seed could be induced into secondary dormancy when exposed to 35°C temperatures under laboratory conditions. Genetics and/or growing conditions of seed-producing plants also influence levels of dormancy that are exhibited by weeds (Murdoch and Ellis 1992).

**Soil Temperature**

Among weed species, there are many different seasonal timings in which peak emergence occurs. This can be partially attributed to differences in optimum temperature for germination. Each weed species has a minimum soil temperature for germination. There is also a maximum temperature, above which germination will not occur. The optimum temperature for emergence, somewhere between the minimum and maximum temperature, is unique for most species. In studies by Weaver and Thomas (1986), percent germination of Powell amaranth (*Amaranthus*
*powellii* was greater than that of redroot pigweed (*Amaranthus retroflexus*) with day and night temperatures less than 25 C, whereas redroot pigweed had greater germination at higher temperatures.

Fluctuation of soil temperature may have as much influence on germination, if not more, than the average soil temperature. Alternating temperatures are important in the breaking of seed dormancy for some species (Martinez-Ghersa et al. 1997). Nishimoto and McCarty (1997) found that only 10% of goosegrass (*Eleusine indica*) seed germinated under constant temperature regimes, whereas 99% germinated under daily fluctuating temperature regimes. As the number of fluctuating temperature cycles increased, so did goosegrass seed germination.

**Soil Moisture**

Water is essential for the hydration and germination of any seed, however available soil moisture can be limiting due to many factors. Much of the diversity in germination among weed species can be attributed to impedance of moisture by structural characteristics of soil and weed seeds. Hard impermeable seed coats of many species, such as velvetleaf, prevent water absorption into the embryo until it has been altered in some form to increase water permeability (Egley, 1986).

The heterogeneity of soils creates a variety of soil microsites with different moisture and aeration conditions that influence seed germination and seedling establishment (Evans and Young, 1972; Harper and Benton, 1966; Harper et al., 1965). Soil water potential frequently determines the timing of seedling emergence (Benech-Arnold and Sanchez, 1994). During periods of reduced water potential,
seed germination is delayed or prevented depending upon the severity of water stress (Bewley and Black, 1982). Although adequate soil moisture is critical to seed germination, in some situations soil water stress can enhance germination. Taylerson (1986) found that giant foxtail seed germination could be increased by the drying of seed after being imbibed with water.

**Light**

Light penetration through crop canopies can be quite variable due to differences in crop growth and/or management practices. Light can significantly affect the germination of certain weed species (Gallagher and Cardina, 1998; Gallagher et al., 1998; Kang-Jin et al., 1997). Gallagher and Cardina (1998) observed 30-55% greater germination of redroot pigweed and giant foxtail due to tillage during the day rather than at night. However, emergence of other species were not affected by tillage timing. Toole and Toole (1940) concluded from their work with goosgrass (*Eleusine indica*) that light was not essential for germination. Botto et al. (1998) observed as much as a 200% increase in weed densities with daytime moldboard plowing compared to nighttime plowing. Botto et al. (1998) concluded, from further studies, that only light at the time of tillage was responsible for triggering germination. Gallagher et al. (1998) explained the effect of light as a photomorphogenic response mediated by the photoreceptor phytochrome. When adequate soil temperatures are attained a labile pool of phytochrome and gibberellic acid, which sensitize seeds to germinate in response to low levels of light, accumulates. They believed this response to be due to an increase in light
harvesting efficiency of seed and or by lowering the far-red light absorbing requirement for germination. Gallagher et al. (1998) also hypothesized that far-red enhanced light, a result of the crop canopy filtering light waves, is responsible for germination inhibition under a canopy. Doroszewski (1997) noticed increased germination of redroot pigweed in red light and decreased germination due to yellow or green light. Doroszewski (1997) also observed that by reducing UV and IR there was an increase in germination, but increasing far red light inhibited germination.

**Organic Matter**

Although herbicides are applied at uniform rates, preemergence herbicides are not always uniformly available within soil solution for uptake by plants. Organic matter is the soil property that has the greatest influence on preemergence herbicide efficacy (Hill et al., 1955; Peter and Weber, 1985a; Peter and Weber, 1985b; Sheets, 1958; Upchurch and Mason, 1962). Reduced herbicidal activity by soil organic matter was most likely due to bonding of herbicide molecules by lipophilic organic-matter surfaces (Weed and Weber, 1974). Soil organic matter is likely more effective at inactivating herbicides with low water solubility (Harrison and Weber, 1975; Lambert, 1967; Leopold et al., 1960) and high adsorptive coefficients ($k_d$) resulting in decreased efficacy of soil applied herbicides such as trifluralin and butralin (Bardsley et al., 1967; Helling, 1976; and Menges and Tamex, 1975).

Interaction between soil organic matter and herbicide efficacy, combined with the heterogeneous nature of soil properties, creates an even more intricate pattern of weed spatial variability. Although most commonly associated with herbicide
efficacy, organic matter also influences environmental conditions (i.e. soil moisture) that impact weed emergence, growth, and seed production. Organic matter influences soil structure and the relative volume of soil pores, which has a direct effect on the soil water matric potential and amount of soil moisture available for plants to absorb (Brady, 1990).

**Soil pH**

Although soil organic matter is the predominant soil factor influencing most soil applied herbicides, other properties such as pH also affect herbicide activity (Harrison et al., 1976; Peter and Weber, 1985a). Adsorption of many herbicides to soil colloids increases as pH decreases (Jenks et al., 1998; Grey et al, 1997; Jourdan et al. 1998). As adsorption of a herbicide increases, bioavailability begins to decrease (Tuxhorn et al., 1997) resulting in lower efficacy.

Changes in herbicide availability due to soil pH may influence weed spatial patterns, although these effects may be confounded by the influence of pH on plant growth and development (Buchanan et al., 1975; McGrath et al., 1982). Considerable research has demonstrated the influence of soil pH on weed flora distribution. LeFevre (1956) observed many cool-season weed species that occurred only within a narrow pH range, whereas Buchanan et al. (1975) observed that both warm-season and cool-season annual weed species differ widely in their response to soil pH. Reduced plant growth in low soil pH areas has been associated with increased solubility of manganese and aluminum as well as decreased availability of calcium and phosphorous (Adams and Lund, 1966; Adams
and Wear, 1957; Foy and Fleming, 1978). Buchanan et al. (1975) suggested that competitiveness of weed species might be decreased by high soil pH.

**Nitrogen**

Factors such as soil nitrogen form, amount and distribution can effect weed germination and spatial pattern. Colliver and Welch (1979) reported that concentrations of ammonium-N exceeding 944 ppm inhibited corn germination. Steinbauer and Grigsby (1957) observed that stimulation of germination occurred due to applications of potassium nitrate. The effects of fertilizer salts on seed germination depend on factors such as solubility and concentration of the fertilizer as well as soil properties and climatic factors (Sardi and Beres, 1996). Effects of nitrogen form seem to vary among weed species. Sardi and Beres (1996) found that velvetleaf (*Abutilon theophrasti* M.) and redroot pigweed germination and growth were inhibited when exposed to high doses of nitrate or ammonium nitrogen (1,000 ppm), but 10-100 ppm increased germination. They concluded that under intensive cropping and fertilization practices an increase of certain weed species can be expected.

Nitrogen has been used to increase yields and competitive ability of crops. However, increased nitrogen does not always increase the crops competitive ability, but rather that of the neighboring weeds. Yield losses of two percent can occur from weed populations of only 1-2 plants per square meter, whereas populations of 20-30 plants per square meter may be needed to cause substantial losses by a different weed species (Wilson, 1989). This is due to the variation in competitiveness
between weed species. Carlson and Hill (1985) observed that wild oat was able to utilize nutrients, such as nitrogen, more efficiently than wheat (*Triticum aestivum* L.). Teyker et al. (1991) noticed that redroot pigweed responded more to supplemental N than maize (*Zea mays*) and accumulated 2.5 times as much N in shoots when supplied with large amounts of N. Weeds require the same nutrients as crops and frequently are more effective in absorbing them (Malicki and Berbeciowa 1986); therefore, a competitive advantage is gained by the weed in many circumstances. Weeds that are more effective at absorbing nitrogen also exhibit rapid growth which increased competition with the host crop for resources such as water and light (Zimdahl 1993).

There is also a differential preference among weed species for different forms of nitrogen (Gigon and Rorison, 1972; Haynes and Goh, 1978). Teyker et al., (1991) found in comparisons of maize and redroot pigweed that maize had no preference between NO$_3^-$ and NH$_4^+$, but there was a 25% reduction of redroot pigweed biomass with NH$_4^+$ compared to the NO$_3^-$.

Salsac et al. (1987) speculated that species able to adapt to high NH$_4^+$ concentrations must be able to compensate for an inadequate supply of absorbed anions relative to cations by a synthesis of organic anions, independent of NO$_3^-$ reduction. Teyker et al. (1991) concluded that maize production could be enhanced while at the same time reducing redroot pigweed competition by increasing NH$_4^+$ levels in the soil.

Besides influencing competition, other aspects of nitrogen and its interactions with weeds need to be taken into consideration. Plant growth responses due to
different nitrogen levels may affect weed seed production. Weeds that utilize nitrogen more efficiently than crops and respond by rapid growth will also be more likely to return more seed to the soil seed bank. Lintell-Smith et al. (1991) observed increases in seed production by 1000 seeds per square meter from *B. sterilis* due to increased nitrogen rates. Nieto and Staniforth (1961) also noticed increased giant foxtail yields due to increased nitrogen rates but corn yields also increased.

**Phosphorous and Potassium**

Inorganic fertilizers are commonly used on a regular basis in agricultural production for improving crop productivity. Although phosphorous and potassium fertilizers are commonly used to improve crop yields, the competitive advantage weeds have over the crop due to increased soil fertility has been widely noted (Alkamper, 1976; Ampong-Nyarko and De Datta, 1993; Jeangros and Nosberger, 1990; Liebman and Robichaux, 1990; Okafor and De Datta, 1976; Sibuga and Bandeen, 1980; Sindel and Michael, 1992; Teyker et al., 1991). The effect of soil nutrients on plant growth and development, has been widely studied, but very few studies have reported the influence of fertilizers on weed seed germination. Sardi and Beres (1996) reported differences in weed responses to both potassium and phosphate salts. Germination of redroot pigweed was directly related to concentrations of both potassium and phosphate, whereas other weed species did not respond to nutrient availability. The influence of fertilizer on seed germination is dependent upon its solubility and concentration along with soil properties and climatic factors such as soil moisture and temperature (Sardi and Beres, 1996). As
soil landscapes and structure change within production fields, so does the availability of many nutrients. The unique relationships that affect nutrient availability and plant growth also further complicate weed spatial patterns.

**Calcium**

Many studies have reported weed species ability to compete for available calcium (Di-Tomaso, 1995; Parylak, 1994; Parylak, 1996; Vengris et al., 1953). Vengris et al. (1953) reported weed species accumulated seven times more calcium than corn growing in competition with the weeds. Competitive advantages of weeds having more efficient nutrient uptake mechanisms than crop species have also been reported (Bhaskar and Vyas, 1988; Bush and Van Auken, 1989; Carlson and Hill, 1986; Cohn et al., 1989; Gonzalez-Ponce, 1988; Moody, 1981; Okafor and De Datta, 1976; Okafor and Zitta, 1991; Peterson and Nalewaja, 1992; Sindel and Michael, 1992), although no strong correlations between weeds and calcium have been made.

**Summary**

Attempts to predict where and when weed populations occur have had limited success due to the multitude of factors influencing weed spatial patterns. One of the most useful characteristics for predicting weed emergence has been soil seed banks. Weed emergence patterns and densities generally are directly related to seed bank patterns and densities. Weed populations can be predicted fairly well using seed banks however, sampling of seed banks at a high enough frequency to create accurate field maps is costly and time consuming. Seed banks do not always
fully represent emergence patterns due to the small portion of viable seed in soil-seed banks that actually emerge. Dormancy levels of weed seed can vary in response to genetic differences among species as well as due to environmental conditions under which seed producing parent plants were exposed.

Confounding effects of soil properties, environmental factors and management practices often decrease relationships between seed banks and emergence. Environmental conditions such as soil moisture and soil temperature are important factors regulating emergence patterns and survival of weeds. Soil moisture can vary in response to the heterogeneous nature of soil types and their water holding capacity and in turn influence weed germination rates as well as growth and development. Environmental conditions within crop canopies can also be quite variable due reduced crop stands caused by factors such as insects, disease, flooding, etc. Underdeveloped areas of crop canopies allow light penetration, needed for germination of many weed species, and provide an extended period of time in which weed seeds can germinate and establish themselves.

Many physical and chemical soil properties have also been found to influence weed spatial dynamics. Fertilizers commonly applied to agricultural fields (nitrogen, phosphorous and potassium) directly influence weed germination, seed production and growth as well as increase weed-crop competition. Other soil properties, such as organic matter and pH, indirectly influence weed dynamics. Increased absorption of soil-applied herbicides due to high soil organic matter has been widely reported.
Persistence of many soil-applied herbicides have also been associated with soil pH levels. Spatial patterns of both OM and pH could significantly influence availability of soil-applied herbicides that were applied at a uniform rate as well as weed spatial patterns.

Objectives

In recent years, advances in technology has led to the ability to apply crop inputs on a site specific basis. Site-specific applications of fertilizers have been effective at redistributing nutrients to areas where yield responses occur, resulting in more efficient use of fertilizers. Site-specific applications of herbicides have also recently been utilized, although little information as to what is driving weed spatial dynamics is available. Many applications are based on spatial patterns of soil characteristics that have been found to affect herbicide performance while ignoring weed spatial patterns. The purpose of this study was to evaluate associations between soil properties and weed presence. Other objectives were to quantify seed banks and emergence within corn-soybean rotations so as to understand the influence of host crops on spatial dynamics of weeds. A better understanding of the relationships between soil properties, environmental conditions, seed banks and weed emergence could help implement more efficient site specific weed management plans.
MATERIALS AND METHODS

Experiment design

A field study was initiated in 1998 and continued through 2000 to observe spatial dynamics of weeds and their relationship with soil and environmental parameters on the Sorenson Research Farm near Ames, Iowa. A transect was established containing 103 one m² quadrats spaced every four m in an east to west orientation across a 98 hectare field. Transect location was chosen in a manner that would include a highly variable array of soil properties and landscape positions. The transect dissected four major soil series common to central Iowa that vary in characteristics such as percent slope, water holding capacity, organic matter, and other soil properties. Soil series within the transect as described by the Iowa soil survey (Wells and Dideriksen, 1981) are listed below.

*Okoboji mucky silt loam*

A fairly level, poorly drained soil with a concave depression that is subject to ponding. Water capacity is typically very high with organic matter ranging between 8 to 16%.

*Harps loam*

A nearly level, poorly drained soil on upland flats and swales. Water capacity is high with organic matter typically ranging from 6-7%.

*Webster silty clay loam*

A nearly level, poorly drained soil on upland flats and drainageways. Water capacity is high with organic matter typically ranging from 6-8%.
*Clarion loam*

A gently sloping, well drained soil on convex upland knolls. Water capacity is typically high with organic matter ranging from 3-4%. Surface layer is generally acidic unless lime has been added.

Previous cropping history of the test area consisted of a corn-soybean rotation using conventional tillage practices. Soil fertility was maintained using recommended crop management practices based on yield goals and soil nutrient test levels. Prairie Brand PB 236 and PB 237 soybeans were planted May 14, 1998 and May 4, 2000, respectively, at a rate of 395,000 seeds per ha in 76 cm rows. Pioneer 34R07 corn was planted on May 10, 1999 at a rate of 68,446 seeds per ha in 76 cm rows. A row cultivation was performed on July 15, 1998 and July 7, 2000. Herbicides, application dates and rates are listed in Table 1.

**Field data collection**

Soil samples were taken within each quadrat along the transect on April 13, 1998 and analyses were performed to determine physical characteristics (percent clay,

<table>
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<th>Date</th>
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silt, sand and organic matter) and chemical properties (pH, phosphorous, potassium, calcium, magnesium, cation exchange capacity and nitrate). Weed species within each quadrat were identified, counted and recorded weekly in 1998, 1999 and 2000. Weeds were not disturbed at time of counting in order to monitor plant survival. Cumulative weed emergence was calculated by summing the maximum weed density prior to postemergence control tactics (herbicides and cultivation) and density of weeds emerging after these strategies. Calculation of cumulative emergence assumes 100 percent weed control due to postemergence strategies. Although control was not 100 percent, a high level of control was attained each of the three years. Soil moisture within the upper 15 cm of soil was measured periodically throughout the growing season seven days after rainfall events using a moisture-point time domain reflectrometry probe. Crop leaf area index (LAI) was taken prior to closure of crop canopy to detect variation in canopy development within the transect using a LiCor 2000 LAI meter.

**Seed bank analysis**

Soil was sampled each spring to quantify the native soil seed bank of the transect. An eight cm diameter soil probe was used to excavate the upper 8-10 cm of soil from six locations in a radial pattern within each quadrat of the transect. Samples within a quadrat were combined and mixed into a composite sample. Seed banks were quantified using methods developed by Buhler and Maxwell (1993). Soil was air dried and sieved through a 5 mesh screen. Six 100 g subsamples were

---

1 ESI Environmental Sensors Inc., 300 Enterprise St., Suite A, Escondido, CA. 92029.
2 LI-COR Inc. Environmental, 4421 Superior St., Lincoln, NE. 68504.
taken from each sample and placed in 250 ml centrifuge bottles with 75 ml of K$_2$CO$_3$. Bottles were equalized in weight using additional K$_2$CO$_3$. Bottles were shaken for 7-10 minutes at 300 rpm and then placed in the centrifuge for 10 minutes at 10,000 rpm. Supernatant from each bottle was strained through a 50 mesh screen. Pellet was rinsed three times with water and then discarded. Rinsate was also strained through a 50 mesh screen. Seed and organic debris recovered were dried at 35 C. Once dried, seeds were separated from organic debris, identified and counted. Subsample seed quantities were averaged by location prior to statistical analysis.

**Statistical analysis**

Traditional descriptive statistics were used to describe site properties, weed seed bank and cumulative emergence. Pearson correlations ($\alpha= 0.01$) were used to describe relationships between site properties and weed species abundance for each year and quadrat location. Semivariograms were constructed for weed seed bank and cumulative emergence data to describe their small scale spatial patterns. Preparation for and construction of semivariograms are described in the following paragraphs.

*Removal of trend.* Data was detrended in preparation for spatial analysis. Seed bank and field population data were transformed using $\log_e (y+1)$ as a result of highly skewed frequency due to a large percentage of the sample sites having no seeds or weed emergence present. Data was then fitted to a polynomial regression model (i.e., $y = A + Bx + Cx^2 + Dx^3$), in which seed bank or field population values ($y$) were a function of distance ($x$) in order to describe the large-scale variation across
the transect. Best fit models were determined using the step-wise selection and removal of coefficients at the $\alpha = 0.15$ level and residuals were used as the new detrended data value. After removal of large-scale trends, the variance structure of the residuals was examined.

**Analysis of semivariance.** The semivariance statistic:

$$\gamma_h = \frac{1}{2}N(h) \sum_{i=1}^{N(h)} [Y(x_i) - Y(x_i + h)]^2$$

where $\gamma_h$ is the semivariance for sample sites separated by distance $h$, $Y(x)$ and $Y(x+h)$ are weed seed bank or cumulative emergence at points $x$ and $x+h$, and $N_h$ is the number of pairs of sample sites separated by distance $h$ (Vieira et al., 1983) was calculated and plotted as semivariograms using the software package GS+\(^3\). Data points with fewer than 50 pairs of sample sites were excluded from semivariograms as they were an unreliable estimator of semivariance (Cressie, 1991; Hamlett, et al., 1986). Prior to plotting semivariograms, data was fitted to spherical models and y-intercept, asymptote, range, percent autocorrelation and $r^2$ values were calculated. Range was calculated as the distance between the y-intercept and asymptote of the semivariograms. Percent autocorrelation was calculated as the semivariance at the y-intercept subtracted from semivariance at the asymptote and divided by the semivariance at the asymptote. This value multiplied by 100 gives the percentage of variation in the data that could be attributable to distance between sample sites.

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\(^3\) Gamma Design Software, P.O. Box 201, Plainwell, MI, 49080
RESULTS AND DISCUSSION

Growing conditions

Temperature and growing degree day data for the 1998 through 2000 growing seasons presented year-to-year variations that are typical of the Midwestern corn belt region. Precipitation accumulation was above normal for the month of June 1998 and the entire 1999 growing season while below normal precipitation amounts were observed throughout the 2000 growing season (Table 2). The above normal precipitation in June 1998 and 1999 resulted in repeated flooding of poorly drained areas and up to 100 percent crop stand losses. Areas with high stand losses were replanted in 1998; however, due to repeated rainfall events, late planting date and weed competition, soybeans were not able to reach physiological maturity. Weed observations from these areas in 1998 and 1999 were ignored due to the inconsistency of crop growth and competition.

Table 2. Monthly, cumulative and 50 year average precipitation for Ames, IA.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>March</td>
<td>60.7</td>
<td>14.7</td>
<td>9.6</td>
<td>60.7</td>
<td>14.7</td>
<td>9.6</td>
<td>53.3</td>
</tr>
<tr>
<td>April</td>
<td>70.3</td>
<td>191.3</td>
<td>26.2</td>
<td>131.3</td>
<td>206.1</td>
<td>35.8</td>
<td>88.6</td>
</tr>
<tr>
<td>May</td>
<td>83.8</td>
<td>134.1</td>
<td>83.6</td>
<td>215.1</td>
<td>340.1</td>
<td>119.4</td>
<td>110.1</td>
</tr>
<tr>
<td>June</td>
<td>249.2</td>
<td>171.2</td>
<td>87.6</td>
<td>464.3</td>
<td>511.3</td>
<td>206.9</td>
<td>130.2</td>
</tr>
<tr>
<td>July</td>
<td>63.5</td>
<td>146.1</td>
<td>66.6</td>
<td>527.8</td>
<td>657.4</td>
<td>273.5</td>
<td>102.1</td>
</tr>
<tr>
<td>August</td>
<td>80.3</td>
<td>143.5</td>
<td>31.1</td>
<td>608.1</td>
<td>800.9</td>
<td>304.5</td>
<td>106.1</td>
</tr>
<tr>
<td>September</td>
<td>25.4</td>
<td>59.7</td>
<td>23.4</td>
<td>633.4</td>
<td>860.6</td>
<td>327.9</td>
<td>80.5</td>
</tr>
<tr>
<td>October</td>
<td>87.6</td>
<td>7.6</td>
<td>17.8</td>
<td>721.1</td>
<td>868.2</td>
<td>345.7</td>
<td>60.7</td>
</tr>
</tbody>
</table>
Variation of site properties

Location for establishment of the transect was chosen so as to incorporate the highest level of variability of soil parameters within the field. The field had an elevation gradient of roughly 5 m that extended from a ridge having well drained coarse textured soils to a closed depression area that was poorly drained (Figure 1). Soil pH ranged from 4.8 to 7.7 and soil parameters with the largest coefficient of variation (CV) were NO3-N, Ca, OM, Bray-1 P and CEC (Table 3). Soil OM, Ca, CEC, pH and moisture were all highly correlated among each other, with correlations ranging from 0.80 to 0.92 (Table 4).

Seed bank and weed densities

Giant foxtail, Setaria faberi (SETFA) and common waterhemp, Amaranthus rudis (AMATA) were the dominant species in the field (Table 5). Velvetleaf (Abutilon theophrasti) and other species were also observed, although at insufficient densities for analysis. SETFA seed banks ranged from 0.7 seeds per 600 g of soil in 1998 to
Table 3. Range of soil characteristics within transect.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Mean</th>
<th>SD</th>
<th>CV</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>log[H+]</td>
<td>6.3</td>
<td>1.2</td>
<td>18.8</td>
<td>4.8</td>
<td>5.6</td>
<td>7.7</td>
</tr>
<tr>
<td>OM</td>
<td>%</td>
<td>5.9</td>
<td>2.5</td>
<td>42.3</td>
<td>2.3</td>
<td>5.5</td>
<td>11.1</td>
</tr>
<tr>
<td>Bray-1 P</td>
<td>mg kg⁻¹</td>
<td>33.4</td>
<td>13.7</td>
<td>40.8</td>
<td>3.0</td>
<td>35.0</td>
<td>65.0</td>
</tr>
<tr>
<td>K</td>
<td>mg kg⁻¹</td>
<td>165.3</td>
<td>36.3</td>
<td>22.0</td>
<td>100.0</td>
<td>160.0</td>
<td>280.0</td>
</tr>
<tr>
<td>Ca</td>
<td>mg kg⁻¹</td>
<td>4114.6</td>
<td>2699.1</td>
<td>65.6</td>
<td>300.0</td>
<td>2700.0</td>
<td>10000.0</td>
</tr>
<tr>
<td>Mg</td>
<td>mg kg⁻¹</td>
<td>466.1</td>
<td>103.8</td>
<td>22.3</td>
<td>250.0</td>
<td>450.0</td>
<td>770.0</td>
</tr>
<tr>
<td>CEC</td>
<td>meq100g⁻¹</td>
<td>27.8</td>
<td>11.2</td>
<td>40.3</td>
<td>8.8</td>
<td>24.6</td>
<td>54.4</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>mg kg⁻¹</td>
<td>6.7</td>
<td>4.8</td>
<td>70.9</td>
<td>2.5</td>
<td>5.5</td>
<td>29.0</td>
</tr>
<tr>
<td>Moisture</td>
<td>%</td>
<td>30.9</td>
<td>6.9</td>
<td>22.4</td>
<td>18.9</td>
<td>29.3</td>
<td>45.8</td>
</tr>
<tr>
<td>Sand</td>
<td>%</td>
<td>50.8</td>
<td>5.9</td>
<td>11.8</td>
<td>40.0</td>
<td>50.0</td>
<td>62.5</td>
</tr>
<tr>
<td>Silt</td>
<td>%</td>
<td>25.9</td>
<td>2.9</td>
<td>11.4</td>
<td>17.5</td>
<td>27.5</td>
<td>30.0</td>
</tr>
<tr>
<td>Clay</td>
<td>%</td>
<td>23.2</td>
<td>3.9</td>
<td>17.2</td>
<td>15.0</td>
<td>22.5</td>
<td>32.5</td>
</tr>
</tbody>
</table>

*OM, soil organic matter; Bray-1 P, phosphate; K, potassium; Ca, calcium; Mg, magnesium; CEC, cation exchange capacity; NO₃-N, nitrate.

1.8 seeds per 600 g in 1999. SETFA seed densities decreased to 1.2 seeds per 600 g of soil in 2000. AMATA seed bank densities were fairly low in 1998 (1.2 seeds per 600 g), but increased by 7.5 and 2 fold between 1998-1999 and 1999-2000, respectively. Cumulative SETFA emergence did not differ among years with densities ranging from 12 to 15 plants m⁻². Although SETFA mean densities were relatively stable between years, AMATA densities increased by 18 fold over the three years with densities ranging from 1.5 plants m⁻² in 1998 to 27 plants m⁻² in 2000. Observations of SETFA and AMATA populations at 0, 2, 4, 6, 8 and 10 weeks after planting (WAP) illustrated different temporal emergence patterns between species and years (Table 6). Below average precipitation in April and May of 1998 may have reduced activity of preemergence herbicides therefore resulting in high
Table 4. Comparison of correlation (r) among soil properties.

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>pH</th>
<th>OM</th>
<th>Pbray</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>CEC</th>
<th>NO$_3$</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Moist</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-</td>
<td>0.92</td>
<td>-0.40</td>
<td>0.40</td>
<td>0.90</td>
<td>-0.45</td>
<td>0.80</td>
<td>0.47</td>
<td>-0.59</td>
<td>0.46</td>
<td>0.55</td>
<td>0.86</td>
</tr>
<tr>
<td>OM</td>
<td>-</td>
<td>-0.16</td>
<td>0.59</td>
<td>0.88</td>
<td>-0.32</td>
<td>0.82</td>
<td>0.35</td>
<td>-0.74</td>
<td>0.58</td>
<td>0.69</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Pbray</td>
<td>-</td>
<td>0.49</td>
<td>-0.32</td>
<td>0.28</td>
<td>-0.26</td>
<td>-0.55</td>
<td>ns</td>
<td>ns</td>
<td>0.21</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>-</td>
<td>0.48</td>
<td>ns</td>
<td>0.50</td>
<td>ns</td>
<td>-0.66</td>
<td>0.55</td>
<td>0.58</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>-</td>
<td>-0.23</td>
<td>0.97</td>
<td>0.31</td>
<td>-0.70</td>
<td>0.55</td>
<td>0.55</td>
<td>0.64</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>ns</td>
<td>-0.21</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>-0.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEC</td>
<td>-</td>
<td>0.26</td>
<td>-0.72</td>
<td>0.60</td>
<td>0.63</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_3$</td>
<td>-</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td></td>
<td></td>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>-</td>
<td>-0.81</td>
<td>-0.90</td>
<td>-0.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>-</td>
<td>0.48</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>-</td>
<td>0.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moist</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ns = correlation not significant at the p=0.05 level*
Table 5. Cumulative emergence and seed bank densities.

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>SETFA (plants m⁻²)</th>
<th>AMATA</th>
<th>Seed bank¹</th>
<th>SETFA (seeds per 600g soil)</th>
<th>AMATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>75</td>
<td>14.6</td>
<td>1.5</td>
<td>0.7</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>1999</td>
<td>75</td>
<td>11.9</td>
<td>11.4</td>
<td>1.8</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>103</td>
<td>15.4</td>
<td>27.0</td>
<td>1.2</td>
<td>19.9</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td></td>
<td>NS</td>
<td>10.6</td>
<td>0.7</td>
<td>7.8</td>
<td></td>
</tr>
</tbody>
</table>

¹ Mean value of all quadrats.

SETFA densities (10.2 plants m⁻²) two WAP. SETFA densities slowly decreased between three to six WAP. Decreases in density may have been attributable to natural mortality or increased herbicide activity as result of several precipitation events in June 1998, which followed a dry period. Few plants emerged after a sethoxydim application six WAP. SETFA populations peaked at 4.6 plants m⁻² four

Table 6. SETFA and AMATA populations 0, 2, 4, 6, 8 and 10 weeks after planting.

<table>
<thead>
<tr>
<th>weeks after planting</th>
<th>SETFA¹</th>
<th>AMATA¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998²</td>
<td>1999³</td>
</tr>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>10.2</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>7.8</td>
<td>4.6</td>
</tr>
<tr>
<td>6</td>
<td>5.9</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>0.1</td>
<td>3.1</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
<td>2.6</td>
</tr>
<tr>
<td>LSD</td>
<td>4.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

¹ Mean value of all quadrats
² Postemergence herbicide applied 6 WAP and row cultivation 8 WAP.
³ Postemergence herbicide applied 5 WAP.
⁴ Postemergence herbicide applied 6 WAP and row cultivation 10 WAP.
WAP in 1999. No herbicides active on SETFA were applied postemergence in 1999. Population densities remained relatively constant throughout the remainder of the season. Emergence began two WAP in 2000, similar to 1998, but densities did not reach their maximum of 10.7 plants m\(^{-2}\) until six WAP, prior to a postemergence application of sethoxydim applied the same week.

AMATA populations were low in 1998 compared to 1999 and 2000, although similar trends in emergence timing occurred in all years. Peak AMATA density was reached six WAP in 1998 with very little emergence occurring after the postemergence application of bentazon and acifluorfen applied later in the week. In 1999, very little emergence (0.6 plants m\(^{-2}\)) occurred prior to a bromoxynil application five WAP and the peak density (7.4 plants m\(^{-2}\)) was not reached until ten WAP. In 2000, the largest AMATA density (19.5 plants m\(^{-2}\)) occurred immediately prior to a postemergence bentazon and acifluorfen application (six WAP). AMATA populations remained relatively high at eight WAP partially due to poor herbicide efficacy and continued emergence. SETFA and AMATA populations were relatively low ten WAP due to a row cultivation that week. The majority of AMATA emergence occurred between four to ten WAP whereas SETFA primary emergence occurred between two to six WAP. Previous work has also found the time of initial AMATA emergence to occur later and continue for a longer period of time than SETFA (Hartzler et al., 1999).
Correlation between site properties and seed banks

Correlations between seed bank or cumulative emergence and site properties were examined to see if relationships existed between one another. Weed seed bank densities were correlated with many of the site properties (Table 7). Among site properties that were examined, pH, OM, Ca and CEC had the strongest correlations (p=0.01) with SETFA and AMATA seed bank densities. SETFA 1998 seed banks demonstrated the weakest correlations of the three years with the four site properties (0.31-0.46). Both 1999 and 2000 SETFA seed banks as well as 1998, 1999 and 2000 AMATA seed banks expressed stronger correlations with these site properties (0.44-0.74). Soil texture was not related to seed bank distribution except in 1999. Both SETFA and AMATA were negatively correlated

### Table 7. Correlation between soil parameters and weed seed bank

<table>
<thead>
<tr>
<th></th>
<th>SETFA</th>
<th>AMATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.39</td>
<td>0.73</td>
</tr>
<tr>
<td>OM</td>
<td>0.46</td>
<td>0.74</td>
</tr>
<tr>
<td>Bray-1 P K</td>
<td>-1</td>
<td>-0.31</td>
</tr>
<tr>
<td>Ca</td>
<td>0.38</td>
<td>0.67</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CEC</td>
<td>0.31</td>
<td>0.57</td>
</tr>
<tr>
<td>N-ppm</td>
<td>-</td>
<td>0.28</td>
</tr>
<tr>
<td>Sand</td>
<td>-</td>
<td>-0.38</td>
</tr>
<tr>
<td>Silt</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clay</td>
<td>-</td>
<td>0.34</td>
</tr>
<tr>
<td>LAI</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>0.39</td>
<td>0.49</td>
</tr>
</tbody>
</table>

1 correlations not significant at the p=0.01 level.
with sand content and positively correlated with percent clay content, but only for 1999. Bray-1 P was also negatively correlated with AMATA all three years and SETFA in 1999 and 2000. Nitrogen was positively correlated with both SETFA and AMATA two out of three years. AMATA seed banks were not correlated with LAI in any of the three years. Two years of SETFA seed banks and one year of AMATA seed banks were correlated with soil moisture.

Correlation of site properties and weed density

Correlations between site properties and weed densities prior to postemergence herbicide application, prior to harvest, and with a calculated cumulative emergence were examined for relationships between site properties and weed distribution (Table 8 and 9). Weed density for each of the three observations demonstrated similar relationships. SETFA densities were strongly correlated with pH, OM and soil moisture prior to postemergence application, at harvest and cumulative emergence. AMATA densities were also highly correlated with the pH and OM with the exception of pH and OM at harvest in 1998 and OM prior to post in 2000. Both Ca and CEC were also highly correlated with SETFA and AMATA densities at all times throughout the season for each year with the exception of the 2000 growing season prior to postemergence and at harvest. Soil nitrate was also highly correlated with SETFA density at each observation timing, except for at harvest in 2000, yet was not associated with AMATA other than in 1999.
Table 8. Correlation of SETFA density and site properties.

<table>
<thead>
<tr>
<th></th>
<th>Correlation (r)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Prior to post(5-6 WAP)</th>
<th>At Harvest (12WAP)</th>
<th>Cumulative emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td></td>
<td>0.46 0.62 0.31</td>
<td>0.69 0.54 0.54</td>
<td>0.67 0.73 0.59</td>
</tr>
<tr>
<td>OM</td>
<td></td>
<td>0.49 0.53 0.34</td>
<td>0.60 0.46 0.52</td>
<td>0.61 0.63 0.58</td>
</tr>
<tr>
<td>Bray-1 P</td>
<td></td>
<td>-0.39 -0.54 -0.53</td>
<td>-0.54 -0.24 -0.24</td>
<td>-0.53 -0.43 -0.29</td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>0.28 0.25 0.29</td>
<td>0.25 -0.24 -0.29</td>
<td>0.29 -0.29 -0.43</td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td>0.41 0.45 -0.28</td>
<td>0.66 0.40 0.41</td>
<td>0.64 0.54 0.48</td>
</tr>
<tr>
<td>Mg</td>
<td></td>
<td>- - -0.28</td>
<td>- - -0.24</td>
<td>- - -0.29</td>
</tr>
<tr>
<td>CEC</td>
<td></td>
<td>0.35 0.32 -</td>
<td>0.58 0.29 0.34</td>
<td>0.55 0.39 0.41</td>
</tr>
<tr>
<td>N-ppm</td>
<td></td>
<td>0.35 0.58 -</td>
<td>0.47 0.50 0.30</td>
<td>0.53 0.58 0.24</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td>- - -0.32</td>
<td>- - -0.34</td>
<td>- - -0.43</td>
</tr>
<tr>
<td>Silt</td>
<td></td>
<td>- - 0.26</td>
<td>- - 0.29</td>
<td>- - 0.37</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td>- - 0.29</td>
<td>- - 0.30</td>
<td>- - 0.37</td>
</tr>
<tr>
<td>LAI</td>
<td></td>
<td>- - -</td>
<td>- - -0.29</td>
<td>- - 0.41 -0.31</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td></td>
<td>0.54 0.56 0.35</td>
<td>0.60 0.45 0.50</td>
<td>0.63 0.63 0.46</td>
</tr>
</tbody>
</table>

<sup>1</sup> Correlations significant at the p=0.01 level unless presented as -.
Table 9. Correlation of AMATA density and site properties.

<table>
<thead>
<tr>
<th>Correlation (r)</th>
<th>Prior to post (5-6 WAP)</th>
<th>At Harvest (12WAP)</th>
<th>Cumulative emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>0.58</td>
<td>0.54</td>
<td>0.29</td>
</tr>
<tr>
<td>OM</td>
<td>0.53</td>
<td>0.511</td>
<td>-</td>
</tr>
<tr>
<td>Bray-1 P</td>
<td>-0.31</td>
<td>-</td>
<td>-0.29</td>
</tr>
<tr>
<td>K</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca</td>
<td>0.56</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CEC</td>
<td>0.50</td>
<td>0.42</td>
<td>-</td>
</tr>
<tr>
<td>N-ppm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sand</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Silt</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clay</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LAI</td>
<td>-0.37</td>
<td>-</td>
<td>-0.37</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>0.47</td>
<td>0.52</td>
<td>-</td>
</tr>
</tbody>
</table>

1 correlations significant at the p=0.01 level unless presented as - .
Comparisons of site property correlations illustrate OM, pH, Ca, CEC and soil moisture influence on weed densities. It is impossible to determine which soil factor has the greatest influence on weed spatial dynamics due to the high correlation among these soil properties (Table 4). It is likely that OM (Hill et al., 1955; Peter and Weber, 1985a; Sheets, 1958; Upchurch and Mason, 1962), pH (Harrison et al., 1976; Peter and Weber, 1985b), CEC and soil moisture (Harrison et al., 1976; Peter and Weber, 1985) affect weed spatial dynamics indirectly through their influence on premergence herbicide efficacy. Due to the irregular spatial patterns of these site properties and their influence on herbicide efficacy, it is suspected that all four properties play an important role in weed spatial dynamics. Other site properties such as Mg, Bray-1 P, LAI and N were related to weed seed bank and emergence in one or more years, yet was not consistently associated with emergence each year. The inconsistency of LAI influence could be attributable to variability of climatic conditions between years or differences in the competitiveness and canopy structure between corn and soybean.

**Correlation of seed bank and cumulative emergence**

Seed bank and cumulative emergence spatial patterns showed very similar trends between each other for all three years (Figure 2 through 5). Seed bank and cumulative emergence density frequency were heavily skewed, with several transect locations having no seed bank or emergence and a few areas having high counts. Quadrats having high seed bank and weed counts were relatively stable between the three years. Field areas in 1998 having high or low SETFA or AMATA densities
Figure 2. Distribution of SETFA seed bank along the transect.

Figure 3. Distribution of SETFA cumulative emergence along the transect.
Figure 4. Distribution of AMATA seed bank along the transect.

Figure 5. Distribution of AMATA cumulative emergence along the transect.
Table 10. Between year correlation for SETFA and AMATA seed banks and cumulative emergence.

<table>
<thead>
<tr>
<th>Years</th>
<th>SETFA seed bank</th>
<th>SETFA cumulative emergence</th>
<th>AMATA seed bank</th>
<th>AMATA cumulative emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 -1999</td>
<td>0.53</td>
<td>0.59</td>
<td>0.66</td>
<td>0.54</td>
</tr>
<tr>
<td>1999 -2000</td>
<td>0.39</td>
<td>0.68</td>
<td>0.52</td>
<td>0.69</td>
</tr>
<tr>
<td>1998 -2000</td>
<td>0.64</td>
<td>0.66</td>
<td>0.38</td>
<td>0.49</td>
</tr>
</tbody>
</table>

1 All correlations significant at the p=0.01 level.

Correlations were significantly correlated (p=0.01) with high and low density areas in both 1999 and 2000 (Table 10). Correlations between 1998 and 2000 were generally larger for both SETFA seed bank and cumulative emergence, where correlations between consecutive years for AMATA were larger. Seed banks of SETFA and AMATA species sampled in the spring of each year exhibited strong correlations with cumulative emergence in the same year (0.39-0.69) (Table 11). Late season weed densities were positively correlated with the following spring seed banks, with the

Table 11. Correlation between spring seed bank and cumulative emergence for each year observations were made.

<table>
<thead>
<tr>
<th>Year</th>
<th>SETFA</th>
<th>AMATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>0.54</td>
<td>0.69</td>
</tr>
<tr>
<td>1999</td>
<td>0.63</td>
<td>0.58</td>
</tr>
<tr>
<td>2000</td>
<td>0.39</td>
<td>0.43</td>
</tr>
</tbody>
</table>

1 All correlations significant at the p=0.01 level.
Table 12. Correlation between weed densities 10 WAP and the following year’s seed bank.

<table>
<thead>
<tr>
<th>Years²</th>
<th>SETFA</th>
<th>AMATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-1999</td>
<td>0.41</td>
<td>0.43</td>
</tr>
<tr>
<td>1999-2000</td>
<td>0.41</td>
<td>ns</td>
</tr>
</tbody>
</table>

¹ All correlations significant at the p=0.01 level.

exception of AMATA seed banks sampled in the spring of 2000 (Table 12).

**Spatial structure of seed bank and cumulative emergence**

Mean seed bank and emergence densities serve as good indicators of overall populations, although they do not effectively describe spatial patterns.

Semivariograms were constructed for weed seed bank and cumulative emergence data to observe changes in variance between sample sites as their separation distance increased (Figures 6 and 7). Corresponding spherical model parameters for these semivariograms are shown in Table 13. Typically, as the distance between sample sites increased, samples become more independent, resulting in higher variances. The rate at which variances increase and the separation distance required before variability ceased to increase can help describe small scale spatial patterns. In 1998 and 2000, the semivariance of SETFA seed banks were not affected by distance between sample sites. Semivariances were close to 0.19 at all separation distances in both years. In 1999 there was a linear response between semivariances and separation distance of sample sites as result of variability
Figure 6. SETFA seed bank and cumulative emergence semivariograms.
Figure 7. AMATA seed bank and cumulative emergence semivariograms.
increasing at a constant rate throughout all separation distances. Although no small scale spatial patterns were observed for seed banks in 1998 and 2000, there was spatial dependence among SETFA cumulative emergence for both years. In both 1998 and 2000, the semivariance of SETFA cumulative emergence increased in a linear fashion up to roughly 58 and 51 meters, respectively, at which point semivariances for separation distances greater than this were similar. The linear portion of the semivariograms represented the spatial dependence of all sample sites up to 58 and 51 meters and is commonly referred to as range. The semivariance at the asymptote of the semivariogram was around 1 for 1998 and 2000, which was 4.5 and 2.6 fold larger than the semivariance at their y-intercepts, respectively. SETFA cumulative emergence semivariance at y-intercepts were 17 and 100 percent larger than the average semivariance of 1998 and 2000 seed

\[ r^2 \]
banks, respectively. Observations of differences between semivariances at the y-intercept and asymptote show that 79 and 62 percent of the variation in SETFA cumulative emergence could be attributed to the distance between sample sites in 1998 and 2000, respectively.

Small scale spatial patterns of the AMATA seed banks varied significantly between all three years. In 1998 semivariance increased sharply out to 12 meters, at which point it remained constant between all separation distances greater than this distance. This could be interpreted that sample sites less than 12 meters apart were dependent upon one another, although the actual increase in semivariance between the first set of separation points and the asymptote, where semivariance no longer increased, was roughly only 0.08 units. Due to the small increase in semivariance over the linear portion of the semivariogram, it would suggest that distance between sample sites did not influence small scale spatial patterns. In 1999 there was a more distinct small scale spatial pattern. Sample sites were dependent up to 41 meters and 50 percent of the variation of AMATA seed banks could be attributed to distance between sample sites. Semivariance levels of 2000 AMATA seed banks were similar at all separation distances due to a lack of dependency between sample sites and therefore could not be fit to a spherical model. In 1998 AMATA cumulative emergence data was weakly fit to a spherical model, although would have been better represented by a linear model due to semivariance increasing at a constant rate for all separation distances. In both 1999
and 2000 there was no spatial pattern present. Semivariance values were around 0.3 and 0.5 for all separation distances, respectively.

Small scale spatial patterns of SETFA and AMATA were highly variable between years for both seed banks and cumulative emergence. In 1998 and 2000, when soybeans were planted following corn in the previous year, the lack of significant models suggest no small scale spatial patterns were evident for SETFA or AMATA seed banks. In 1999, the year following soybeans, both SETFA and AMATA seed bank semivariances were dependent upon distance between sample sites. Semivariances being dependent upon distance suggests that 1999 seed banks presented more of a patchy distribution than in 1998 and 2000.

Comparisons of cumulative emergence in all three years resulted in opposite trends as were exhibited by seed banks. SETFA cumulative emergence in 1998 and 2000, the years soybeans were planted, showed a strong small scale spatial pattern within 58 and 51 m; however in 1999 when corn was planted no spatial pattern found. From observations of relationships between seed banks and cumulative emergence, primarily SETFA, assumptions could be made that weed spatial pattern within soybeans also reflect weed seed production spatial variability. The variability of seed production is then captured in the spatial pattern of seed banks the following spring. The lack of spatial pattern for cumulative emergence in the year corn was planted and the following year’s seed bank could suggest that differences in factors such as corn and soybeans competitive ability, rate of canopy closure or canopy architecture might influence future spatial patterns. Continued observation of weed
patterns in the future could strengthen hypothesis of host crop influence on weed spatial patterns.
SUMMARY AND CONCLUSIONS

Over the course of time in which observations were made environmental conditions varied. Cumulative precipitation between March and October of 2000 was less than half of that in 1998 or 1999; however, SETFA cumulative emergence was equivalent to prior years and AMATA cumulative emergence increased. SETFA seed bank densities were also similar between years; while AMATA seed banks gradually increased each year in the same manner cumulative emergence did. Continuous increases of AMATA cumulative emergence were most likely due to previous year seed rain rather than the current years environmental conditions, since emergence densities were highest in 2000 when precipitation was less than half of the previous year.

Initial time and length of emergence was consistent within species for all three years. Emergence of AMATA occurred primarily between four to ten WAP whereas SETFA emergence began at two WAP with few plants emerging later than six WAP, which coincides with previous findings. Hartzler et al. (1999) found SETFA initial time of emergence to be earlier and the mean time of emergence slightly shorter than AMATA. Peak emergence for SETFA and AMATA fluctuated slightly each year. In 1998, most SETFA emergence occurred between one to two WAP, whereas in 1999 and 2000, the biggest percentage occurred at three to four WAP. The largest percentage of AMATA emergence occurred two to three weeks later in 1999 than in 1998 or 2000. Delayed emergence in 1999 could be attributable to differences in canopy structure while in the corn phase of crop rotation.
Large scale spatial patterns of both species were consistent from year to year. High correlations of seed banks with cumulative emergence of the same year (0.39-0.69) and with cumulative emergence in following years (0.43-0.60) suggested that seed banks could serve as a good estimator of future weed spatial patterns.

Occurrence of SETFA and AMATA seed banks and cumulative emergence were more frequent within field areas having high pH, OM, CEC and soil moisture values. The consistent association between weeds and these properties could be due to interactions between site properties and herbicide efficacy rather than direct effects on the weeds. Interactions between weeds, herbicide efficacy and these four soil properties have been widely noted in previous studies (Ghidey et al., 1997; Blumhorst et al., 1990; Peter and Weber, 1985a). Clay content, which was also associated with emergence in some years, has also been found to influence herbicide adsorption (Rai et al., 2000) and dissipation (Clay et al., 2000). Other associations with weed densities in some years included a negative relationship with crop LAI as result of weed densities being more common in areas with less dense crop canopies. Lindquist et al. (1998) observed decreased seed production and biomass of velvetleaf with increases in crop LAI, although this response was not consistent in all years. It is likely that spatial patterns of these site properties and their interactions could also influence the highly variable spatial patterns of weeds commonly observed in production agriculture fields.

In 1999, the year following soybeans, spatial dependency of SETFA and AMATA seed banks were present. Spatial dependency also existed for SETFA
cumulative emergence in years soybeans were planted. AMATA emergence patterns also showed spatial dependency for one of the two years soybeans were planted. However, there were no spatial relationships present for seed banks of either species in the years (1998, 2000) following corn or for cumulative emergence in the years corn was planted in rotation after soybean. Hypotheses could be formed that corn is more competitive than soybean either due to differences in canopy architecture or rate of canopy closure. Continuation of this research in the future could help support hypotheses suggesting differences among corn and soybean influence on weed spatial patterns.

Interpretation of weed spatial patterns could be useful for development of scouting and sampling methods. Semivariograms created for 1998 and 2000 SETFA cumulative emergence suggested one sample every 51 to 58 meters would adequately describe weed spatial patterns, whereas in 1999 when no spatial pattern was present, a few random samples could be used to describe populations within this transect. Random sampling is appropriate if samples are independent and variance is uniform throughout the field (Cochran, 1977). Since only data from the transect was used in these semivariogram, implications about unsampled areas outside the transect could not be made. Semivariograms using seed bank data taken in a uniform grid sampling pattern could be beneficial in determining an efficient approach to scouting or weed management in the future.

The primary objective of this study was to see if relationships exist between soil properties and weed emergence, which might influence the spatial patterns of
weeds. Weeds were correlated with several soil properties, although the relationship between weeds and these soil properties might be an indirect effect of interactions between herbicide efficacy and soil properties. In high input agricultural systems, factors such as herbicides most likely override the effect soil properties may have on spatial dynamics. Community structure and plant composition in ecosystems not subjected to high levels of inputs such as mineral fertilization or herbicides are more likely to be directly influenced by nutrient availability (Huenneke et. al., 1990).
REFERENCES


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