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WEED CONTROL AND HERBICIDE TOLERANCE

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INTERSEEDED COVER CROPS IN SEED CORN PRODUCTION: WEED CONTROL AND HERBICIDE TOLERANCE

By

Brent E. Tharp

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ABSTRACT

INTERSEEDED COVER CROPS IN SEED CORN PRODUCTION: WEED CONTROL AND HERBICIDE TOLERANCE

By

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Field studies were conducted in 1995 and 1996 to determine the effect of interseeded cover crops on grass weeds. Cover crop treatments containing annual ryegrass reduced the density of grass weeds 75 days after seed corn planting. However, differences in visual grass control among cover crop treatments were not apparent at corn harvest. Additional field studies were conducted in 1995 and 1996 to determine the most appropriate time to seed annual ryegrass and crimson clover following an application of a preemergence herbicide. Annual ryegrass was not successfully established following metolachlor, but was successfully established at an interval of time following an application of EPTC and pendimethalin. Crimson clover was not successfully established when it was seeded the same day herbicides were applied, but was successfully established at an interval of time following an application of pendimethalin, EPTC and metolachlor.

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CHAPTER 1

Review of the Literature

Introduction. Cover crops offer many potential benefits to agriculture production systems. They can reduce water and wind erosion (Smith et al. 1987; Frye et al. 1983; Pieters and McKee 1938), sequester excess nitrates (Shipley et al. 1992; Jackson et al. 1993), provide nitrogen to succeeding crops (Wilson and Hargrove 1986; Wagger 1989; Mitchell and Teel 1977), improve soil properties (Hoyt and Hargrove 1986; Benoit et al. 1962), provide a favorable environment for predatory insects (Clark et al. 1993; Bugg 1990; Kaakeh and Dutcher 1993), and suppress weeds through allelopathy, competition, and/or physical effects (Lal et al. 1991). The suppression of weeds has been demonstrated with cover crop residues and live cover crop plants (Worsham 1991).

Weed management, in agronomic production systems requires a significant amount of time, energy, and resources. In seed corn production, growers will often use a combination of herbicides and cultivation to reduce the level of weeds. This management system has not been consistently effective, particularly with weeds which emerge late in the growing season. Many of the management practices associated with seed corn production, such as detasseling and irrigation, create a favorable environment for weed infestation. A cover crop seeded after corn emergence might compete enough with late emerging weeds to provide sufficient suppression of the weeds. This type of cover cropping system is known as interseeded or overseeded cover crops. Many times interseeding cover crops will follow a previous herbicide application. Little information is available regarding the susceptibility of cover crop species to commonly used herbicides. The research contained in this thesis will encompass the use of interseeded cover crops to reduce annual grass infestation in seed corn, and review the potential use of corn herbicides in cover crops.

Cover Cropping Systems

Numerous terms in literature are used to describe cover cropping systems. Some terms describe the way cover crops are used: catch crop, smother crop, and green manure. Other terms are an actual description of the cover cropping system: living mulch and winter cover crop, while some terms describe how the cover crops are established: spring seeded, interseeded, or overseeded. All of these terms are accurate descriptions of cover cropping systems, and many times the terms can be used interchangeably.

Catch crop. A catch crop is usually made in reference to a cover crop which has been established in order to sequester excess nutrients, primarily nitrates. In agriculture, nitrogen fertilizer is often applied in amounts which exceed crop requirements. The excessive amounts of nitrogen often result in nitrate contamination of groundwater (Baker and Johnson 1981; Angle et al. 1993; Roth and Fox 1990). Many studies have shown cover crops can be used to reduce the levels of nitrate contamination (Martinez and Guiraud 1990; Staver and Bronsfield 1990; Jackson et al. 1993; Eisenbeis 1994). The cover crop should be established near maturity of a row crop, yet early enough to allow sufficient biomass accumulation. Uptake of nitrates will continue as the cover crops accumulate biomass. Martinez and Guiraud (1990) and Staver and Bronsfield (1990) reported that annual ryegrass *(Lolium multiflorum)* and cereal rye (*Secale cereale* L.) removed large amounts of nitrates from the soil profile. Shipley et al (1992) concluded that grass cover crops conserved more residual nitrogen than legumes. Cover crops may effectively remove nitrates, however they eventually release nitrates and additional nutrients (Miller et al. 1994). The eventual release of sequestered nutrients should be considered when a catch crop is going to be used. Research has been conducted investigating the release of nitrogen from cover crop residues, and how the release could correspond to an actively growing crop (Dou 1995; Wilson and Hargrove 1986; Wagger 1989a).

Smother crop. The term smother crop is primarily used in reference to a cover crop that is used for the purpose of weed control. Smother crops can control weeds through physical competition for light and water, and through the inhibitory action of allelopathic substances (Overland 1966; DeHaan et al. 1994). A more comprehensive discussion on the use of cover crops for weed control will be included in a latter section of this literature review.

Green manure. Pieters and McKee (1938) differentiated between a cover crop and a green manure crop. They described the function of a cover crop "to prevent erosion and leaching, to shade the ground, or to protect the ground from excessive freezing and heaving." Their description of the function of a green manure was "to add organic matter to the soil. As an incident to this function the nitrogen supply of the soil may be increased and certain minerals made more readily available, these effects in turn increase the productivity of the soil".

Living mulch. In a living mulch/row crop system, the living mulch is established prior to row crop establishment, and the row crop is established directly into all or a portion of a suppressed or actively growing cover crop species.

Many of the field trials involving living mulch systems have focused on weed control, management of the mulches, and the effect of the mulches on the associated row crop. Field trials using grass and legume mulches in no-till corn production have revealed comparable corn yields are achievable depending on the species of mulch used (Elkins et al. 1983; Echtenkamp and Moomaw 1989). Elkins et al. (1983) showed good corn yields could be obtained while maintaining up to 60% of a living mulch. Turfgrasses and legumes were investigated for use as living mulches in sweet corn production at Cornell University (Nicholson and Wien 1983; Vrabel et al. 1980). Chewing fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), and 'Kent' white clover *(Trifolium repens* L. 'Kent') did not adversely affect the yield of sweet corn. However, other species have been reported to decrease corn yields (Echtenkamp and Moomaw 1989; Nicholson and Wien 1983,). The use of living mulches is not just confined to the United States. Akobundu and Okigbo (1984) reported the successful use of a living mulch system in maize production in Nigeria.

Some investigators have tested the use of perennial legumes as living mulches. Hartwig (1990) has investigated crownvetch (*Coronilla varia* L.) living mulch systems, while Illnicki and others (Illnicki and Enache 1992; Illnicki and Vitolo 1986) have investigated the use of subterranean clover (*Trifolium subterraneum* L.). Research conducted by Ranells and Wagger (1992) and Kumwanda et al (1993) have focused on developing an annual legume, crimson clover (*Trifolium incarnatum* L.), into a perennial living mulch system.

Winter cover crops. A winter cover cropping system should provide ground cover throughout the winter season. Winter cover crops can be established while a row crop is growing, but are often established after the row crop has matured or has been harvested. This system is similar to a living mulch system except that the plants are destroyed, either by chemical or mechanical means or by natural winterkill. The remaining residues are often left as a mulch, and the row crop is no-till planted directly into the mulch. Compounds, which are potentially phytotoxic to crops, are often released during decomposition of the residues (Chase et al. 1991; White et al. 1989). If a sensitive crop is going to be planted directly into a mulch, planting should be delayed at least two weeks after the cover crop has been killed (Raimbault et al. 1991). Removal of cover crop residues within the row combined with selected in-furrow treatments may reduce the interval between cover crop destruction and row crop planting (Dabney et al. 1996).

Cereal rye is a popular winter cover crop species, and conflicting data exists regarding the effects of a rye cover crop in corn production. Moschler et al. (1967) reported that corn yields were sometimes increased when corn was grown in the presence of a rye mulch. Soil moisture was also conserved in his field trials. Decreased corn yields was reported by Eckert (1988). He felt the decreased yields were a result of reduced corn populations in rye treatments, which is consistent with results published by Mitchell and Teel (1977).

Legumes may be a better choice for a winter cover crop species and have been shown to increase corn yields (Holderbaum et al. 1990; Decker et al. 1994; Smith et al. 1987; Torbert et al. 1996). Holderbaum et al (1990) concluded that nitrogen availability will be reduced in legume/small grain cover cropping systems, because the small grain will immobilize the nitrogen. Wagger (1989a) concluded that winter annual legume cover crops are capable of providing a substantial portion of nitrogen to a succeeding crop. In his field trial the production of corn dry matter was higher for legume cover crops as compared to a rye cover crop. Grain sorghum following a legume cover crop did not respond to the addition of nitrogen fertilizer, but did respond to as much as 99 kg N/ha when following a rye cover crop (Hargrove 1986). Winter cover cropping systems using hairy vetch (*Vicia villosa* Roth.) have produced encouraging results (Clark et al. 1995; Frye and Blevins 1989). Scientists at the University of Kentucky have estimated hairy vetch can supply the equivalent of 90-100 kg/ha of nitrogen fertilizer (Ebelhar et al. 1984; Blevins et al. 1990).

Many of the potential benefits from winter cover cropping systems depend on how the cover crops are managed prior to row crop planting. Emergence and growth of corn and cotton were not effected when planted into soils containing legume residues; however, the dry weight of corn was increased when the legume residue was placed on the surface (White et al. 1989). Many scientists have investigated how nitrogen dynamics are effected by management of cover crops (Wilson and Hargrove 1986; Wagger 1989b; Karlen and Doran 1991). Dabney et al. (1991) investigated the use of mechanical methods to manage cover crops, while other studies focused on management by chemical means (Peters and Dest 1975; Weston 1990; Dabney and Griffin 1987). Clark et al. (1995) reported that grain yields were higher when hairy vetch was killed later in the spring as compared to early killed hairy vetch. They concluded that soil water conservation by late killed vetch mulches had a greater influence on corn production than vetch water use in the spring (Clark et al.1995). On the other hand, Munawar et al. (1990) reported yields were significantly greater with early killed rye than late-killed rye. They believed allowing a cover crop to grow up to the time of corn planting may adversely affect the subsequent corn crop by competing for soil water. However, they also felt that during years of high spring rainfall, it may be advantageous to allow the cover crop to grow longer in order to dry out the soil and produce more dry matter for surface mulch, which would conserve more water for the corn crop during the summer (Munawar et al.1990). Research conducted by Hesterman et al. (1992) revealed that the yield of corn following a winter cover crop increased when soil water was adequate at the time of corn planting. However, when spring precipitation was below normal the yield of corn following a winter cover crop was reduced (Hesterman et al. 1992).

Soil temperature under a mulch is another important factor to consider when using a winter cover crop. Fortin and Pierce (1991) reported that corn development was delayed when soil temperatures under the mulches were 2.2°C lower than bare soil temperatures.

Spring seeded. Spring seeded cover crops are established from late winter up to planting of a row crop. Many species of cover crops have been successfully established in the spring (Nelson et al. 1991). In an evaluation of multiple establishment periods, Stute and

Posner (1993) found that cover crops which were established in the spring had the largest amount of biomass. Spring planted rye resulted in lower or comparable soybean yields in a field trial in Minnesota (Warnes et al. 1991). Ateh and Doll (1996) believed rye could be planted in the spring without a reduction in soybean yield if weed pressure was low, ground cover and soil moisture were adequate, and rye interference was minimal.

DeHaan et al. (1994) investigated multiple interference durations of spring seeded yellow mustard in corn production. Using principles explained in previous weed interference studies, they believed it was possible that a spring seeded cover could reduce weed populations and have only a small impact on corn yield. They reported that yellow mustard grown with a corn crop for four weeks, and grown to a maximum height of 10 cm resulted in an average corn yield reduction of 4%.

Interseeded/Overseeded. The terms interseeded and overseeded are used synonymously throughout literature pertaining to cover crops. An interseeded crop is seeded directly into a row crop. A potential problem associated with interseeded crops involves competition between interseeded crops and row crops (Exner and Cruse 1993; Kurtz et al. 1952). Competition is the relationship between two or more plants in which the supply of a growth factor falls below their combined demands (Aldrich 1984). A crop growing between the rows of another crop will compete for nitrogen and water (Kurtz et al. 1952). Much of the literature pertaining to competition in row crops has dealt primarily with weed/crop competition (Zimdahl 1980; Aldrich 1984; Schmenk 1994; Fausey 1996). When giant foxtail was left to a height of at least 30.5 cm, corn yields were significantly reduced due to the competitive effects of giant foxtail (Knake and Slife 1969). Corn yields were significantly reduced when giant foxtail was seeded the same day the corn was planted (Knake and Slife 1965). Hall et al. (1992) reported that the critical period of a weed free environment began between 3-14 leaf corn and ended on average at 14 leaf-stage corn. Therefore, it would be possible to establish an interseeded crop in a row crop production system without sacrificing yield of the row crop. Based on the results of competition studies, the most appropriate time to seed an interseeded crop would be at some point after row crop planting.

Early research involving interseeded crops focused primarily on establishment of the crops for the purpose of forage production (Tesar 1957; Pendleton et al. 1957; Hayes 1958; Nordquist and Wicks 1974). Recent research of interseeded systems has focused on using interseeded species as cover crops rather than forages. The primary objective for much of the interseeded cover crop research has focused on how cover crop species affect the row crop; whereas, with an interseeded forage system, much of the research focused primarily on the performance of the forage crop. Although the results of interseeded forage studies might be based on a slightly different objective, the results of forage research can be directly applied to the management of interseeded cover crops. For instance grass species tested by Hayes (1958) provided more cover than legumes. In the field trials of Pendleton et al. (1957), corn yields decreased as the width between corn rows increased, and a trend of lower yields occurred when alfalfa was interseeded compared to clear seeded. Corn grain yields were reduced when alfalfa was seeded the same day of corn planting and at the time of final row cultivation, but the yield of the first cutting of alfalfa a year after seeding was highest when alfalfa was seeded the same day of corn planting (Nordquist and Wicks 1974). Pendleton et al. (1957) mentioned that when growers are contemplating using an interseeded cropping system, they must first determine their objectives in order to properly choose their management practices.

Interseeded cover crops are seeded from the time of row crop establishment up to the time of row crop harvest. The time of cover crop seeding is an important factor to consider in an interseeded cover cropping system. Pendleton et al. (1957) believed that the earlier the interseeded crop was seeded the more likely yields would be reduced. Corn yields were reduced when cover crops were seeded the same day of corn planting (Exner and Cruse 1993; Vrabel et al. 1980); however, soybeans yields were not reduced at this seeding time (Robinson and Dunham 1954). Seeding cover crops near the time of a final inter-row cultivation is another popular time to establish interseeded cover crops, and reduction in grain yields were not apparent when cover crops were seeded near this time (Helsel et al. 1991; Scott et al. 1987; Nanni and Baldwin 1987; Eadie et al. 1992)

The effect of seeding time on cover crop establishment is dependent on species and weather conditions (Exner and Cruse 1993; Palada et al. 1983; Keeling et al. 1996; Vrabel et al. 1980). Small seeded cover crop species interseeded into cotton were more dependent on rainfall than larger seeded species (Keeling et al. 1996). Ground cover from the interseeded cover crops was usually greater than the treatments without a cover crop (Stute and Posner 1993; Scott et al. 1987; Vrabel et al. 1980; Eadie et al. 1992). Scott and Burt (1987) reported that interseeded cover crops provided as much cover and yielded as much forage as the cover crops which were seeded without a row crop.

Cover crops have been shown to provide a favorable habitat to both predatory and pest insects (Bugg and Ellis 1990). Interseeding red clover (*Trifolium pratense*) into a corn crop reduced the level of corn damage by European corn borer (*Ostrinia nubilalis* Hübner) (Lambert et al. 1987). The population of generalist predatory insects increased as the amount of ground cover increased (Clark et al. 1993). Kaakeh and Dutcher (1993) reported crimson clover and hairy vetch were preferential hosts to *Acyrthosiphon pisum* Harris., which is an alternate prey of generalists predators. Maintaining alternate prey on cover crops could potentially attract higher densities of natural enemies (Bugg and Dutcher 1989).

Weed Control with Cover Crops

Allelopathy. Putnam and Duke (1978) defined allelopathy as the detrimental effect of higher plants of one species on the germination, growth, or development of plants of another species. The detrimental effect of allelopathy is exerted through release of chemicals by the donor plant (Putnam and Duke 1978). Williams and Hoagland (1982) have investigated the effects of phenolic compounds on germination of weed and crop seed. Extracts of rye were shown to inhibit the germination and growth of lettuce (*Lactuca setiva* L.) (Power 1991) and barnyardgrass (*Echinochloa crus-galli* L.) (Chase et al. 1991), while effects on the germination and growth of cucumber (*Cucumis sativus* L.) and snap bean *(Phaseolus vulgaris* L.) were variable (Chase et al. 1991). Overland (1966) reported the inhibition of common chickweed (*Stellaria media* L.) growth and germination from exposure to aqueous leachates of barley (*Hordeum vulgare* L.). Aqueous extracts of wheat (*Triticum aestivum* L.) reduced the germination and growth of pitted morningglory (*Ipomoea lacunosa* L.) and common ragweed (*Ambrosia artemisiifolia* L.) (Stute and Posner 1993), while aqueous extracts of various legumes inhibited the germination and growth of corn (*Zea mays* L.), cotton (*Gossypium hirsutum*), and wild mustard (*Brassica kaber*) (White et al. 1989). Shettel and Balke (1983) applied five allelopathic chemicals at multiple timings and rates to a variety of weed and crop species. Most of the chemicals applied preplant incorporated at rates as high as 56 kg ha^{-1} reduced the growth of corn, soybean, velvetleaf (*Abutilon thoephrasti* Medic.), redroot pigweed (*Amaranthus retroflexus* L.), and wild proso millet *(Panicum miliaceum*). Postemergence applications of caffeine and hydroquinone inhibited the growth of the weed species more than the crop species (Shettel and Balke 1983).

Weed control in cover crop residues. The management of allelopathic cover crop residues is one way allelopathy could be used in cropping systems (Weston 1996). Suppression of weeds have been demonstrated in many field trials using cover crops (Worsham 1991b; Einhellig and Leather 1988; Putnam et al. 1983; Gliessman 1983). Allelochemicals, that are released from rye residues, can reduce weed seed germination and seedling growth (Barnes and Putnam 1987). Rye residues have been shown to be phytotoxic to cress (*lepidium sativum* L.), lettuce, barnyardgrass, and proso millet (*Panicum miliaceum* L.) in a soil bioassay, and the phytotoxic compounds were degradable (Barnes and Putnam 1986). Greenhouse and field studies revealed that residues from brassica cover crops reduced the growth and emergence of some weed species (Boydston and Al-Khalib 1994).

Hairy vetch residue suppressed the establishment of some weed species under shaded conditions more than under full sunlight conditions, suggesting light was a more important factor than allelopathy or physical impedance (Teasdale 1993). In no-till corn production, weed suppression by cover crops was variable (Teasdale and Daughtry 1993; Hoffman et al. 1993; Curran et al. 1994). Curran et al. (1994) concluded that differences in early evaluations weed densities were greater than late evaluations of weed densities. Teasdale et al. (1991) reported a reduction of total weed density in rye or hairy vetch residue, when the cover crop biomass exceeded 300 g/m and covered more than 90% of the soil. Weed suppression occurred in hairy vetch and rye cover crops which were mowed prior to no-till corn planting (Johnson et al. 1993; Mangan et al. 1995). However, corn growth and yield often suffered from this strategy of cover crop management (Johnson et al. 1993; Hoffman et al. 1993; Curran et al. 1994). Greater than 90% weed control in rye mulch was reported in a no-till soybean production system (Liebel et al. 1992). Another soybean field trial revealed inconsistent results of weed suppression when rye, wheat, and triticale (X *Triticosecale Wittmack* 'OAC Wintr') cover crops were used (Moore et al. 1994). In a strawberry (*Fragaria x aranassa* Duch.) production system, rye and wheat mulch provided greater early season weed suppression than barley (*Hordeum vulgare* L. 'Barsoy') (Smeda and Putnam 1988).

Weed control in live cover crops. Weed levels in an interseeded cover cropping system were less than in a corn monoculture system (Mt. Pleasant and Scott 1991). Rye seeded in the spring at 168 kg/ha reduced the biomass of weeds as compared to rye seeded at 56 kg/ha (Ateh and Doll 1996). A subterranean clover living mulch system provided excellent weed control without the use of herbicides (Enache and Ilnicki 1990; Ilnicki and

Enache 1992). Hartwig (1976) reported a reduction in the growth of yellow nutsedge (*Cyperus esculentus*) from a crownvetch living mulch. Living mulches in sweet corn production effectively suppressed weeds (DeGregorio and Ashley 1986; Vrabel et al. 1980). A living mulch of ladino clover (*Trifolium repens* L.) reduced the biomass of weeds, but the yield of no-till sweet corn was also reduced (Galloway and Weston 1996). Vrabel et al. (1980) concluded weed suppression was better for earlier seeded cover crops, but sweet corn yields were also reduced at this seeding time. A similar trend was apparent with spring seeded yellow mustard; as the duration of interference increased weed dry weights decreased and corn grain yields decreased (DeHaan et al. 1994). Echtenkamp and Moomaw (1989) stated that a living mulch could control the growth of weeds, but could also compete with corn for soil water when rainfall is below normal. In general, live cover cropping systems have the potential to suppress weeds, but yields of the row crop are often reduced.

Seed Corn Production

Corn was an established crop in North America before the arrival of the first European explorers. Christopher Columbus once reported that his brother passed through eighteen miles of corn, which had been raised by the Indians. The Indians taught the early colonists how to raise corn and many of our modern corn varieties can be traced back to the corn types obtained from the Indians (Bressman and Wallace 1949). The corn raised in post colonial days were a result of random crosses of flint, dent, and gourdseed corn types (Bressman and Wallace 1949). The flint-dent crosses became the predominant crop raised in the midwest region of the United States, and a large portion of the midwest eventually became known as the "corn belt".

In the 1870's W. J. Beal of Michigan State University was one of the first scientists to work with controlled crosses. His research along with more in-depth research of Dr. G. H. Shull and Dr. E. M. East at Connecticut eventually led to the introduction of hybrid corn (Bressman and Wallace 1949). Hybrid corn is a cross of two or more unrelated lines of corn, known as inbreds (Bickner 1993). The progeny of the cross will often yield higher than the parent lines, and this enhanced performance is often referred to as hybrid vigor (Sprague 1992). Hybrid vigor was a primary reason hybrid corn was adopted in the United States. Before the introduction of hybrid corn, farmers would choose corn seed from the previous year and then plant this seed the following year. This process was known as open pollination (Bickner 1993). In 1933 about one percent of the corn grown in the corn belt was a hybrid, and in 1955 nearly all corn grown in the United States was a hybrid (Airy et al. 1961).

If seed from a hybrid is planted the succeeding year, the yield from the succeeding crop will be reduced. Therefore, the use of hybrid seed requires the production of new seed each year (Airy et al. 1961). An industry, comprised of both large and small companies, has evolved which is responsible for the production of new hybrid seed. The larger companies manage all aspects of seed corn production, from the development of new inbreds to the final sale of the hybrid seed. The large diversity of hybrids sold by seed corn companies require maintenance and multiplication of parental inbred seed lines. The inbred lines are the basic foundation of the commercial hybrids, hence the name foundation seed (Craig 1977). Most foundation seed is grown in isolation, usually at least 400m from other corn (Jugenheimer 1976), and is managed by trained technicians (Steele 1978). These stringent measures are used in order to ensure genetic purity of the foundation seed. Smaller seed companies will often purchase the foundation seed from companies who specialize in foundation seed production (Craig 1977). Foundation seed is used for producing hybrid commercial corn seed (Jugenheimer 1976). Foundation seed is often grown by farmers under contract agreements with seed corn companies (Steele 1978). Most agronomic practices used in seed corn production such as fertilizing, planting, and pest management are similar to commercial corn production, but are under the supervision of the seed corn company (Wych 1988).

Many of the current commercial hybrids are a result of single crosses or modified single crosses (Wych 1988). A single cross is the progeny of two inbred lines. One inbred is used as the male pollen bearing parent, while the other inbred is used as the female seed bearing parent. The two inbred parents are planted in the same field and are isolated from other corn fields. An important aspect of seed corn production involves assuring that an abundant supply of pollen is present when the female inbred is in the silk stage. In order to ensure enough pollen is produced, male and female inbreds are often planted in patterns of 4:1 (four rows of female to one row of male), 4:2, 4:1:4:2, 6:2, or solid female with the male rows interplanted (Wych 1988). Techniques are also used in order for the female and male parents to flower on the same date, which is known as a "nick". These techniques could include clipping or flaming the pollen parent, planting the parents at different times, variable fertilizer rates, or different planting depths (Craig

1977). The pollen parent is often destroyed after pollination is complete, thereby eliminating the possibility of seed contamination from the pollen parent (Craig 1977).

Another critical factor in seed corn production involves ensuring pollen of the seed parent is not produced. Various methods for pollen control are utilized. These include detasseling, cytoplasmic sterility, genic male sterility, and chemical pollen control (Craig 1977). The two most common methods are detasseling and cytoplasmic male sterility (Wych 1988). Detasseling involves removal of the tassel from the seed parent either manually or in combination with mechanical operations (Wych 1988). Detasseling is ultimately the responsibility of the seed corn company (Steele 1978).

Seed corn is often harvested when the seed has reached physiological maturity (Wych 1988), which is typically much earlier than commercial corn harvest. The contract grower is usually responsible for corn harvest (Wych 1988). The corn is generally harvested on the ear, and transported to the seed corn facility where the corn is eventually sorted, husked, dried, shelled, cleaned, sized, treated, and bagged (Wych 1988). During all of these processes the corn is handled in such a manner as to minimize damage of the corn seed, because damaged seed will result in reduced germination. The final step in seed corn production is selling the corn. Most seed corn companies will use a farmer-dealer system in conjunction with their own sales staff (Wych 1988).

Although many of the agronomic practices for seed corn production are similar to commercial corn production, the production of seed corn requires more intense management inputs, and involves more risks. Inbred seed are inherently weak, emerge later, and grow more slowly than many of the commercial hybrids. Smaller growing inbreds, detasseling, and male corn row removal will reduce the competitiveness of the corn, which is an important factor in weed control (Harvey 1994). Herbicides are heavily relied on for weed control in the seed corn industry (Craig 1977), but not all herbicides are safe on all inbreds (Widstrom and Dowler 1994; Green et al. 1997). Therefore, the infestation of weeds is a major concern in seed corn production.

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CHAPTER 2

Evaluation of Interseeded Cover Crops for Suppression of Grass Weeds in Seed Corn Production

Abstract. Seed corn fields in southwest Michigan are often infested with high populations of grass weeds. These grasses create harvesting difficulties and can reduce corn yield. Studies were conducted in seed corn fields in St. Joseph County, Michigan in 1995 and 1996 to examine the potential of interseeded cover crops for suppression of grass weeds. Dominant grass species were fall panicum in 1995 and large crabgrass in 1996. Annual ryegrass, crimson clover, and an annual ryegrass + crimson clover mixture were seeded over plots that were treated, at seed corn planting, with metolachlor or EPTC. The cover crops were seeded when the seed corn was in the V4-V6 growth stage. Metolachlor was more injurious to annual ryegrass than EPTC. Annual ryegrass plots following metolachlor had significantly lower height and density compared to plots following EPTC. Crimson clover following metolachlor were not reduced in density or height. Grass weed densities were recorded 75 days after seed corn planting for cover crop treatments which followed EPTC. The annual ryegrass and the annual ryegrass + crimson clover mixture had lower grass weed density than where no cover crop was seeded. Crimson clover alone did not significantly reduce grass weed densities. Visual ratings 112 days after planting revealed no apparent differences in grass control among treatments seeded with cover crops or between cover crop treatments and plots with no

cover crop. Interseeded cover crops did not sufficiently control annual grass weeds.

Nomenclature: EPTC, *S*-ethly dipropyl carbamothioate; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; fall panicum, *Panicum dichotomiflorum* Michx. # PANDI; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; annual ryegrass, *Lolium multiflorum* L.; crimson clover, *Trifolium incarnatum* L. # TRFIN; corn, *Zea mays* L.

Additional index words: EPTC, metolachlor, cover crops, interseeded, overseeded, seed corn production, layby herbicide application.

Abbreviations: DAP, days after planting.

INTRODUCTION

Seed corn production is a major agriculture industry in southwest Michigan. A potential problem with this production system is the infestation of weeds. Weeds compete with seed corn for water and nutrients, and can interfere in harvesting operations. The management practices used in raising a crop of seed corn, such as irrigation, removal of the male corn row, and detasseling, create an ideal environment for the establishment of weeds. Weeds also flourish in seed corn production due to the inherent weakness of inbred plants. Harvey and McNevin (1990) reported that the amount of weed control in a vigorous field corn crop was greater than in a less vigorous sweet corn crop. Harvey (1994) suggested seedbed preparation, management of crop competition, row cultivation, rotary hoeing, crop rotation, preventive measures, and herbicides are techniques that could be used in an integrated approach to control weeds in seed corn production. The use of a row cultivation following an application of a preemergence herbicide has been shown to enhance weed control in a field corn production system (Mulder and Doll 1993). Seed corn producers in southwest Michigan usually apply a preemergence herbicide and use row cultivation later in the season for weed management. This weed management system will often provide sufficient control of early season weeds, but control of late emerging weeds, primarily annual grasses, is inconsistent. Seed corn producers will often apply a herbicide at the time of final row cultivation to control late emerging annual grasses. This method of herbicide application is commonly referred to as a layby application.

Cover crops have been shown to reduce weed populations in many agronomic production systems (Ateh and Doll 1996; Ilnicki and Enache 1992; Einhelling and Leather 1988). The reduction of weed densities by cover crops can be attributed primarily to physical competition between weeds and the cover crop, or by allelopathic interactions of cover crop residues (Lal et al. 1991; Putnam et al. 1983). Mt. Pleasant and Scott (1991) have reported weed suppression by interseeded cover crops in a field corn production system. This type of cover cropping system could easily be incorporated into a seed corn production system, because the environment, which favors the infestation of weeds, can be ideal for establishment of a cover crop.

This trial was conducted to determine the effect of interseeded cover crops on annual grass weeds in a seed corn production system, and to determine the effect of cover crops on seed corn yield. The effect of EPTC and metolachlor on annual ryegrass and crimson clover was evaluated in this field trial. The effect of a layby metolachlor application on grass weed control was also investigated in this field trial.

MATERIALS AND METHODS

Field trials were established in seed corn production fields in St. Joseph County Michigan in 1995 and 1996. The soil was a Spinks sandy loam (sandy mixed, mesic Psammentic Hapludalfs) with a pH of 6.5 and 1.1% organic matter in 1995. In 1996, the soil was a Spinks sandy loam (sandy mixed, mesic Psammentic Hapludalfs) with a pH of 6.8 and 1.6% organic matter. Dates of field operations and experimental measurements are found in Table 1. Primary tillage consisted of fall moldboard plowing in 1995, and fall chisel plowing in 1996. Secondary tillage in 1995 consisted of a field cultivation, and in the spring of 1996 the plot area was disked and field cultivated. In 1995 114 kg/ha of fertilizer (15% N, 15% P_2O_5, 2% K_2O) was applied adjacent to the corn rows during planting and 37 kg/ha of actual nitrogen was dribbled in the form of urea ammonia nitrate at row cultivation on June 13, 1995. In 1996 91 kg/ha of fertilizer (15% N, 15% P_2O_5, 2% K_2O) was applied adjacent to the corn rows during planting and 39 kg/ha of actual nitrogen was dribbled June 26, 1996. Seed corn inbreds were planted in a pattern of four female inbreds to one male inbred in 76 cm rows on May 15, 1995 and on May 18, 1996. The entire plot area was irrigated with center pivot irrigation (Table 2). The field was irrigated to maintain an available water capacity greater than 60%.

The experimental design was a two factor randomized complete block with four replications. The factors were cover crop treatments and herbicide application. Treatments included annual ryegrass, crimson clover, a mixture of annual ryegrass + crimson clover, and no cover crop seeded over plots treated with a preemergence application of either 4.84 kg/ha EPTC or 1.68 kg/ha of metolachlor. In 1995 and 1996, annual ryegrass was seeded at 28 kg/ha, crimson clover was seeded at 17 kg/ha, and an annual ryegrass + crimson clover mixture was seeded at 21 kg/ha + 12 kg/ha. Treatments including annual ryegrass seeded at 56 kg/ha, crimson clover seeded at 34 kg/ha and an annual ryegrass + crimson clover mixture seeded at 42 kg/ha + 24 kg/ha were added in 1996. Treatments including crimson clover were inoculated with *Rhizobia* species in 1996. Other treatments included a layby application of metolachlor, a weed free control, and an untreated check. The layby application of 1.12 kg/ha metolachlor was applied after final row cultivation.

Cover crops were broadcast seeded over 20 cm tall seed corn in the V4 growth stage on June 12, 1995, and 46 cm tall seed corn in the V6 growth stage on June 24, 1996. In 1995, a tractor mounted Gandy air seeder[1] was used to seed the cover crops, and in 1996 the cover crops were seeded using a shoulder harness whirl seeder. Plots were cultivated June 13, 1995 and June 26, 1996. Preemergence herbicides were applied with a tractor mounted compressed air plot sprayer using 8003 flat fan nozzles calibrated to deliver 187 L/ha at a pressure of 207 kPa. Approximately 1.3 cm of irrigation was provided shortly after herbicide applications in order to incorporate the EPTC. Preemergence herbicides were applied on May 17, 1995 and on May 20, 1996. Layby treatments were applied in 76 cm bands using 8003E even flat fan nozzles calibrated to deliver 117 L/ha at 207 kPa. Layby treatments were applied on June 13, 1995 and June 27, 1996.

The densities of cover crop species and annual grass weeds were measured within four 25 by 38 cm quadrats for each plot. The measurements were recorded 75 days after seed corn planting. Fall panicum was the predominant grass weed species present in 1995, and large crabgrass was the predominant species in 1996. Heights of five randomly chosen cover crops were measured with a meterstick. Visual weed control ratings were recorded in all treatments for grass weeds near the time of harvest in both 1995 and 1996. The rating scale ranged from 0 (no apparent weed control) to 100% (complete weed control). The annual ryegrass cover crop was severely injured from preemergence applications of metolachlor. Therefore, weed densities and control ratings in plots which

[1] Gandy Company; Owatonna, Minnesota 55060

were treated with a preemergence application of metolachlor are not reported. The seed corn was harvested for yield determination in 1995, but not in 1996 due to a harvesting error. A 9 m section of a middle corn row was harvested by hand and weight and moisture were recorded. Grain yields were adjusted to a 15.5% moisture level. Cover crop densities, cover crop heights, grass weed densities, grass weed control ratings, and yields were analyzed using analysis of variance. The density of the grass weeds in the untreated plots were significantly higher in 1996 as compared to 1995, however treatment by year interactions were not significant. Therefore, data were combined over years. Means were separated using the least significant difference procedure at the 0.10 level of significance for grass weed density comparisons, and at the 0.05 level of significance for cover crop height, cover crop density, and grass weed control comparisons.

RESULTS AND DISCUSSION

Cover crop injury. The height and density of interseeded annual ryegrass and crimson clover were used to quantify potential injury of the cover crops. EPTC and metolachlor had no effect on the height or density of crimson clover. The height and density of annual ryegrass was significantly reduced when annual ryegrass was seeded into plots previously treated with metolachlor as compared to plots previously treated with EPTC (Table 3). Annual ryegrass injury from metolachlor was severe enough to negatively impact any possible weed suppression from the annual ryegrass. Past research has revealed potential reduction in germination and growth of interseeded cover crops from preemergence herbicides that are still persistent in the soil at the time of cover crop seeding (Cramer 1986; Scott and Burt 1987). EPTC has a shorter soil persistence than metolachlor (Anonymous 1994), and has been successfully used in many previous interseeded cover crop research trials (Scott and Burt 1987; Scott et al. 1987; Stute and Posner 1993).

Grass weed suppression from cover crops. The density of annual grass weeds, 75 days after seed corn planting, was reduced in plots seeded with annual ryegrass and the annual ryegrass + crimson clover mixture as compared to plots without a cover crop (Table 4). The density of the grass weeds in plots seeded with crimson clover were equal to the density of grass weeds in the plots without a cover crop. Visual differences in control of the grass weeds at corn harvest (112 days after seed corn planting) were not apparent (Table 4). Suppression of weeds in a corn production system interseeded with cover crops has been previously reported (Mt. Pleasant and Scott 1991).

Weed suppression from an interseeded cover crop could be attributed to factors associated with plant competition. Aldrich (1984) described competition as being a relationship between plants in which the supply of a growth factor, such as water, light, carbon dioxide, or nutrients falls below the combined demands. Most, if not all, acres of seed corn are irrigated, therefore, the competition for water is generally low. A canopy provided from an interseeded cover crop would compete with the late emerging grass weeds for light, especially if the cover crop was established before weed emergence. In 1996, the seeding rates of the cover crops were doubled to determine the effect of increased cover crop densities on grass weed suppression. Increasing the cover crop seeding rates did not significantly effect the density or visual control of the grass weeds at corn harvest (data not reported). The cover crops in our field trials did not suppress grass weeds to an acceptable level. The growth characteristics of annual ryegrass and crimson clover in relation to the growth characteristics of grass weeds might have contributed to the lack of sufficient grass weed control. Annual ryegrass and crimson clover are cool season plants (Sarrantonio 1994), while fall panicum and large crabgrass are warm season grasses (Stubbendieck 1994). If fall panicum or large crabgrass germinate near the time cover crops are seeded, the rapid growth of the grass weeds would probably eliminate any potential competition for light that a cover crop might provide. A warm season cover crop species that could be established before weeds emerge, and not compete with corn for water might be a more suitable interseeded cover crop for seed corn production.

Layby applications of metolachlor. The addition of a layby application of metolachlor increased grass control as compared to plots without a layby treatment (Table 5). This occurred where either metolachlor or EPTC was applied at planting. The layby treatments provided greater than 85% control of the grass weeds throughout the entire growing season. Previous research has shown that layby herbicide applications generally provided season long control of weeds and reduced weed seed production (Moomaw et al. 1983; Moomaw and Marten 1984).

Seed corn yields. In 1995, differences in seed corn yields were not apparent between cover crops which were seeded into plots treated with EPTC (Table 6). Seed corn yields were reduced in plots that were seeded with the annual ryegrass + crimson mixture and treated with a preemergence application of metolachlor. Interseeded cover crops have been established in field corn without reducing corn yield (Helsel et al. 1991; Eadie et al.

1992).

Cover crops were successfully established following a prior application of EPTC. However, a preemergence application of metolachlor severely injured the annual ryegrass cover crop. Treatments containing annual ryegrass reduced the density of grass weeds at midseason. However, the reduction in grass weed densities did not result in increased grass control at seed corn harvest. Although seed corn production is well suited for interseeded cover crops, substantial suppression of weeds was not observed in this study.

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Table 1. Dates of field operations and experimental measurements.

	1995	1996
Seed corn planting	May 16	May 18
Application of preemergence herbicides	May 17	May 20
Cover crop seeding	June 12	June 24
Final cultivation	June 13	June 26
Application of layby metolachlor	June 13	June 27
Grass weed densities / cover crop heights and densities	July 31	August 2
Grass control ratings	September 7	September 6
Seed corn harvest	September 7	September 18

Table 2. Rainfall and irrigation amounts during an 11 week period of the 1995 and 1996 growing season.

Weeks after cover crop seeding	1995		1996	
	Irrigation	Rainfall	Irrigation	Rainfall
	---------- cm ----------			
-1	0	0.76	0	4.57
0	0	0	1.52	0
1	3.81	0	2.54	0
2	0	3.68	5.08	0.76
3	1.91	0.76	2.54	0.76
4	3.18	2.54	0	0
5	1.27	4.57	0	2.29
6	0	1.32	2.54	0.25
7	0	5.33	5.08	0.64
8	1.78	0	0	1.91
9	0	4.57	0	0
total	11.95	23.53	19.30	11.18

Table 3. Effect of preemergence herbicides on cover crop density and height 75 days after seed corn planting, 1995 and 1996.

	Annual ryegrass		Crimson clover	
	Density	Height	Density	Height
	plants/m^2	cm	plants/m^2	cm
Metolachlor	221 b[a]	14 b	174 a	13 a
EPTC	358 a	20 a	149 a	15 a

[a]Numbers followed by the same letter within columns are not significantly different according to Fisher's Protected LSD Test at $\alpha = 0.05$

Table 4. Effect of cover crops on grass weed density 75 days after seed corn planting and grass weed control 112 days after seed corn planting, 1995 and 1996.

Treatment[a]	Grass weeds	
	Density 75 DAP	Control 112 DAP
	plants/m^2	% of untreated
Annual Ryegrass	19 b[b]	66 a[c]
Crimson Clover	32 a	64 a
Annual Ryegrass + Crimson Clover mixture	12 b	64 a
No cover crop	31 a	65 a

[a]All plots were treated with EPTC prior to seed corn planting

[b]Numbers followed by the same letter within this column are not significant according to Fisher's Protected LSD Test at $\alpha = 0.10$

[c]Numbers followed by the same letter within these columns are not significant according to Fisher's Protected LSD Test at $\alpha = 0.05$

Table 5. Effect of layby metolachlor applications on grass control 112 days after seed corn planting, 1995 and 1996.

	Metolachlor[a]	EPTC[b]
	Control[c]	
	------------ % of untreated ------------	
Layby	88 a	86 a
No layby	77 b	65 b

[a]Treated with a preemergence application of metolachlor

[b]Treated with a preemergence application of EPTC

[c]Numbers followed by the same letter within columns are not significant according to Fisher's Protected LSD Test at $\alpha = 0.05$

Table 6. Effect of cover crops on seed corn yield, 1995.

Treatment	Metolachlor[a]	EPTC[b]
	Yield	
	--------1000 kg/ha--------	
Annual Ryegrass	4.5 ab[c]	3.8 a
Crimson Clover	4.4 ab	4.2 a
Annual Ryegrass + Crimson Clover mixture	3.7 b	3.6 a
No cover crop	5.1 a	3.5 a

[a]Treated with a preemergence application of metolachlor

[b]Treated with a preemergence application of EPTC

[c]Numbers followed by the same letter within columns are not significant according to Fisher's Protected LSD Test at $\alpha = 0.05$

CHAPTER 3

Potential Use of Corn Herbicides in Annual Ryegrass and Crimson Clover Cover Cropping Systems

Abstract. Greenhouse trials were conducted to determine the effect of preemergence and postemergence herbicides on annual ryegrass, oat, crimson clover, and medium red clover. EPTC, flumetsulam + metolachlor, metolachlor, and pendimethalin were tested and each injured annual ryegrass. EPTC, flumetsulam + metolachlor, and metolachlor also injured oat. Crimson clover and medium red clover were significantly injured from flumetsulam + metolachlor and metolachlor. The effect of EPTC and pendimethalin on both clover species was variable. Primisulfuron and nicosulfuron severely injured the annual ryegrass and oat. Response of both grass species to bromoxynil and 2,4-D amine was variable. Bentazon did not injure either of the grass species. All of the postemergence herbicides injured the crimson clover and medium red clover. Field trails were conducted in 1995 and 1996 to determine the required time interval between an application of a preemergence herbicide and seeding of annual ryegrass and crimson clover to avoid herbicide injury. Annual ryegrass was not successfully established after an application of metolachlor. Establishment of annual ryegrass at an interval of time following EPTC was successful. Annual ryegrass seeded after pendimethalin was not successfully established in 1995, but was successfully established in 1996. Crimson clover was injured when seeded the same day the herbicides were applied. Crimson

clover was successfully established when seeded at an interval of time following application of pendimethalin, EPTC or metolachlor. In all cases, successful establishment of the cover crop was dependent on the time interval between herbicide application and cover crop seeding.

Nomenclature: bentazon, 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide; bromoxynil, 3,5-dibromo-4-hydroxybenzonitrile; dicamba, 3,6-dichloro-2-methoxybenzoic acid; EPTC, *S*-ethly dipropyl carbamothioate; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; nicosulfuron, 2-[[[[(4,6-dimethoxy-2-pyrimidynil) amino]carbonyl]amino]sulfonyl]-*N*,*N*-dimethyl-3-pyridinecarboxamide; pendimethalin, *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; primisulfuron, 2-[[[[[4,6-bis(diflouromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl] benzoic acid; 2,4-D (2,4-dichlorophenoxy)acetic acid; annual ryegrass, *Lolium multiflorum*; crimson clover *Trifolium incarnatum* L. # TRFIN; oat, *Avena sativa* L. # AVESA; red clover, *Trifolium pratense* L. # TRFPR.

Additional index words: bentazon, bromoxynil, dicamba, EPTC, metolachlor, nicosulfuron, primisulfuron, 2,4-D amine, cover crops, interseeded, overseeded

INTRODUCTION

Cover cropping systems offer many potential benefits to agriculture (Lal et al. 1991; Bugg 1991; Frye et al. 1983). One type of successful cover cropping system includes the use of interseeded cover crops. In an interseeded cover cropping system a cover crop is seeded directly into a growing row crop. Interseeded cover crops provide ground cover and have been shown to yield as much forage as cover crops grown outside of a row crop (Stute and Posner 1993; Scott and Burt 1987). A popular establishment time for interseeded cover crops is at final row cultivation, and past research has revealed no apparent reductions in row crop yields when cover crops were seeded near this time (Scott et al. 1987; Helsel et al. 1991; Eadie et al. 1992). According to Exner and Cruse (1993), interseeded cover crops should be established in an environment with low weed populations.

In row crop production, herbicides and tillage are often used to reduce weed populations. Many of the herbicides used in row crop production can be harmful to an interseeded cover crop, and application of these herbicides will often determine the time an interseeded cover crop can be seeded (Olson et al. 1986; Scott and Burt 1987; Cramer 1986). Scott and Burt (1987) investigated the establishment of interseeded red clover following an application of EPTC, which is a herbicide with short soil persistence (Anonymous 1994). The herbicide treatments in their trials did not injure the interseeded red clover. Many of the field research trials investigating interseeded cover crops have used EPTC, or a combination of EPTC and other banded herbicides (Olson et al. 1986; Scott et al. 1987; Stute and Posner 1993). In 1987, Cramer published a list of empirical involving herbicide use in cover crops has focused primarily on using the herbicides for cover crop suppression (Hartwig and Hoffman 1975; White and Worsham 1990; Griffin and Dabney 1990). Little information exists on using herbicides to control weeds in a living cover crop, and the effect of the herbicides on the cover crop. Likewise, the effect of previously applied herbicides on cover crop establishment and growth is not well understood. Such information is needed in order to gain the most benefits from an interseeded cover cropping system.

The objectives of our research were to investigate the effect of corn herbicides on cover crops grown in greenhouse conditions, and to determine the required time interval between an application of a preemergence herbicide and seeding of annual ryegrass or crimson clover to avoid herbicide injury.

MATERIALS AND METHODS

Greenhouse Trials. Studies were conducted in the greenhouse to determine the effect of preemergence and postemergence herbicides on cover crop species. Environmental conditions were maintained at 27°C ± 5°C with a 16 hour photoperiod of natural lighting supplemented with metal halide lighting giving a midday photosynthetic flux of 700μE/m^2/s. All herbicides were applied with a continuous link belt sprayer equipped with an 8001E flat fan nozzle calibrated to deliver 234 L/ha of solution at a pressure of 221 kPa.

The cover crops for the postemergence herbicide trial were seeded into 945 ml plastic pots filled with Baccto[1] professional potting mix and were watered as needed. Plants were thinned to four annual ryegrass, three oat, four crimson clover, and four medium red clover plants per pot prior to herbicide application. Bentazon (1.12 kg/ha), bromoxynil (0.42 kg/ha), dicamba (0.56 kg/ha), nicosulfuron (0.035 kg/ha), primisulfuron (0.040 kg/ha), and 2,4-D amine (0.56 kg/ha) were applied to 10 cm annual ryegrass, 18 cm oat, 5 cm crimson clover, and 5 cm medium red clover. Liquid urea ammonium nitrate (28% nitrogen) at 4% v/v and non-ionic surfactant at 0.25% v/v were added to primisulfuron and nicosulfuron, while crop oil concentrate at 1% v/v was added to bentazon. Plant heights were measured 14 days after herbicide application and the aboveground portion of the plants were harvested. The harvested shoots were dried in a 38°C oven for at least three days at which time dry weights were measured.

In the preemergence greenhouse trial, ten seeds of each cover crop species were seeded into 945 ml pots filled with a Spinks loamy sand soil (sandy, mixed, mesic Psammentic Hapludalfs) with 1.0% organic matter and a pH of 6.5. The seeded pots were subsequently treated with 2.35 kg/ha flumetsulam + metolachlor, 2.24 kg/ha metolachlor, and 1.68 kg/ha pendimethalin. Cover crops were also seeded into pots previously treated with 4.48 kg/ha EPTC. EPTC was applied to 470 ml of soil and incorporated by thoroughly mixing the treated soil in a plastic bag. The number and height of emerged plants were measured 28 days after herbicide application and the aboveground portion of the plants were harvested. The harvested shoots were dried in a 38°C oven for at least three days at which time dry weights were measured.

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[1]Baccto is a product of Michigan Peat Co. Houston, TX 77098

The preemergence and postemergence trials were repeated in time and were designed as a randomized complete block with six replications for the preemergence herbicide trial and four replications for the postemergence herbicide trial. Data were analyzed using analysis of variance, and means were separated using Fisher's protected least significant difference test at the 0.05 level of significance. Treatment by run interactions were significant, therefore the data for each run are reported separately.

Field Trials. A field trial seeded with annual ryegrass and a field trial seeded with crimson clover were each established at the Michigan State University Agronomy Research Farm at East Lansing in 1995 and 1996. The soil was a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) with 2.6% organic matter and a pH of 6.5 in 1995, and 2.5% organic matter and a pH of 6.4 in 1996. The site was chisel plowed in the fall of 1994, and moldboard plowed in the fall of 1995. Secondary tillage consisted of spring disking and field cultivation. In 1995, 140 kg/ha of fertilizer (6% N, 24%P_2O_5, 24%K_2O) was broadcast prior to field cultivation, while 336 kg/ha of fertilizer (6% N, 24%P_2O_5, 24%K_2O) was broadcast in 1996. All herbicides were applied with a tractor mounted compressed air plot sprayer using 8003 flat fan nozzles calibrated to deliver 187 L/ha at a pressure of 207 kPa. Precipitation data from the research trials are listed in Table 1.

The field trials were designed in a split block arrangement with four replications. Both trials were arranged in a similar fashion with the strips of cover crop seeded perpendicular to the strips of herbicide application. On May 18, 1995 and May 7, 1996 metolachlor at 1.68 kg/ha, pendimethalin at 1.68 kg/ha, and EPTC at 4.48 kg/ha were applied. The EPTC was incorporated using a field cultivator. Annual ryegrass was seeded at 28 kg/ha and crimson clover was seeded at 17 kg/ha using a grain drill, and the strips were cultipacked. Seeding dates corresponded to the growth stage of corn that was grown adjacent to the plots. The seeding dates are reported in Table 2. Five foot buffer strips were used between each strip of herbicide application in order to compensate for potential dragging of treated soil during seedbed preparation.

Cover crop densities, heights, and visual injury were measured 30 days after the cover crops were seeded. Plants in two one meter sections of row, and heights of five randomly chosen cover crop plants were recorded. Visual injury ratings ranged from 0 to 100%, with 0 representing no injury and 100% indicating complete death of the plant. All data were analyzed using analysis of variance, and means were separated using Fisher's protected least significant difference test at the 0.05 level of significance. Treatment by year interactions were significant, therefore data are reported separately for each year.

RESULTS AND DISCUSSION

Greenhouse preemergence herbicide trials. EPTC, flumetsulam + metolachlor, and metolachlor severely injured annual ryegrass (Table 3). In the first run of the experiment no annual ryegrass plants emerged following an application of these herbicides, and only a small number of annual ryegrass plants emerged in the second run of the experiment. The emergence of annual ryegrass after an application of pendimethalin was reduced in the first run of the experiment but was not reduced in the second run. However, the dry weight of the plants that did emerge was reduced at least 30% to that of the untreated plants. Based on the results of this trial, annual ryegrass appears to be sensitive to EPTC, flumetsulam + metolachlor, metolachlor, and pendimethalin.

Practically no oat plants emerged following an application of EPTC (Table 3). The emergence and dry weight of oat plants following an application of flumetsulam + metolachlor and metolachlor was significantly reduced as compared to the untreated oat plants. Pendimethalin had no significant effect on the growth or emergence of oat plants. The results from this trial would suggest that oat is sensitive to EPTC, flumetsulam + metolachlor, and metolachlor, but is tolerant of pendimethalin.

The emergence and dry weight of crimson clover following an application of flumetsulam + metolachlor were significantly reduced in both runs of the experiment (Table 4). Metolachlor reduced the emergence and dry weight of crimson clover in the first run of the experiment. When the experiment was repeated, the emergence was not reduced but the dry weight was reduced. EPTC did not reduce the emergence of crimson clover in either run of the experiment. However, the dry weight of crimson clover was reduced 47% in the second run. The emergence and dry weight of crimson clover was not significantly reduced from an application of pendimethalin. Crimson clover appears to be most sensitive to flumetsulam + metolachlor and metolachlor. Injury to crimson clover from EPTC could be expected based on the results of this trial. Data would suggest some tolerance of crimson clover to pendimethalin.

Application of flumetsulam + metolachlor and metolachlor severely reduced the emergence and dry weight of medium red clover (Table 4). Pendimethalin reduced the emergence and dry weight of medium red clover in the first run of the experiment. However, the dry weight and emergence were not affected in the second run of the experiment. EPTC did not reduce the emergence or dry weight of medium red clover in either run of the experiment. Medium red clover was sensitive to flumetsulam + metolachlor and metolachlor, but was very tolerant of EPTC.

Greenhouse postemergence herbicide trial. Applications of nicosulfuron and primisulfuron severely reduced the dry weight and height of annual ryegrass (Table 5). The height of annual ryegrass was not reduced when treated with dicamba. However, the dry weight of the plants in the second run of the experiment was reduced. Bromoxynil reduced the dry weight but not the height of annual ryegrass. Bentazon and 2,4-D amine did not affect the dry weight and height of annual ryegrass. Data from this trial would suggest that annual ryegrass is very sensitive to nicosulfuron and primisulfuron, and tolerant of bentazon and 2,4-D amine. Injury to annual ryegrass is possible from applications of dicamba or bromoxynil.

Primisulfuron and nicosulfuron severely reduced the height and dry weight of oat (Table 5). Bromoxynil, dicamba, and 2,4-D amine did not reduce the dry weight and height of oat in the first run of the experiment. However, a small reduction in oat dry weight from these herbicides was apparent in the second run. The height and dry weight of oat were not affected by bentazon. The results from this trial suggest oat plants are quite sensitive to nicosulfuron and primisulfuron. Oat appeared to have fair tolerance to applications of bentazon, bromoxynil, dicamba, and 2,4-D amine.

All of the herbicides reduced the dry weight of crimson clover (Table 6).

However the height of crimson clover was not reduced from bentazon in the first run of the experiment, and 2,4-D amine in the second run of the experiment. Crimson clover appears to be sensitive to all of the herbicides tested in this trial.

The dry weight of medium red clover was reduced from all of the herbicides tested, except for 2,4-D amine in the second run of the experiment (Table 6). The height of medium red clover was not reduced from bentazon or 2,4-D amine in either runs of the experiment. The results of this trial suggest partial tolerance of medium red clover to bentazon and 2,4-D amine, and practically no tolerance to the rest of the herbicides tested.

Field trials. Previously reported greenhouse trials have revealed potential annual ryegrass and crimson clover injury from EPTC, metolachlor, and pendimethalin (Tables 3 and 4). EPTC, pendimethalin, and metolachlor were chosen for these field trials based on the relative persistence of the herbicides in the soil. Metolachlor has been reported to have the longest soil half life of the three herbicides, and EPTC has the shortest (Anonymous 1994). These herbicides are generally applied to the soil before emergence of a row crop.

Annual ryegrass field trials. Annual ryegrass was severely injured from metolachlor regardless of seeding time in 1995 and 1996, and the visual injury was often greater than 90% (Table 7). Annual ryegrass density was significantly reduced from pendimethalin at all seeding times in 1995. However, annual ryegrass height and density were not reduced from pendimethalin when it was seeded at the fourth timing in 1996. The height and density of annual ryegrass, seeded at the fourth timing in 1995 and the third timing in 1996, were not reduced from EPTC.

Based on the results of these trials, establishment of annual ryegrass following an application of EPTC has little risk provided the ryegrass is seeded at least 40 days following application. Establishing annual ryegrass following an application of pendimethalin would involve more risk based on the observed injury in this trial. Results from this field trial suggest annual ryegrass should not be seeded up to seven weeks following an application of metolachlor to minimize risk of herbicide injury.

Crimson clover field trials. Crimson clover was significantly injured and the height was reduced when it was seeded the same day EPTC, metolachlor, and pendimethalin were applied (Table 3). However, crimson clover density was not reduced at this seeding time. The density and height of crimson clover were not reduced from pendimethalin when the clover was seeded at the second timing in both years. Crimson clover injury was less than 20% and plant density was not reduced when the clover was seeded at the third timing following application of EPTC and metolachlor in 1995 and 1996.

Susceptibility of a cover crop to a herbicide and the soil persistence of the herbicide are important factors in the risk of herbicide injury to interseeded cover crops. Crimson clover establishment was possible provided that the crimson clover was seeded at some time interval following application of the herbicides tested. The results from this trial indicate crimson clover could be established sooner following an application of pendimethalin than metolachlor or EPTC.

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Table 1. **Rainfall amounts during a 13 week period of the 1995 and 1996 growing season.**

Weeks after preemergence herbicide application	1995	1996
	cm	
-1	0.25	0.23
0	2.29	2.77
1	3.00	4.93
2	0.36	0.38
3	0.53	0.69
4	0	2.92
5	2.67	0.28
6	4.39	10.16
7	0.46	0
8	3.15	0
9	2.62	0.56
10	0.36	0.20
11	4.11	0.08
total	24.19	23.20

Table 2. Cover crop seeding dates.

	Corn Growth Stage[a]	1995		1996	
		Date	DAT[b]	Date	DAT[b]
Timing 1	at planting	May 18	0	May 7	0
Timing 2	V1-V2	June 2	15	May 24	17
Timing 3	V3-V4	June 14	28	June 11	35
Timing 4	V5-V6	June 26	40	June 25	49

[a]Growth stages of corn grown adjacent to the cover crop
[b]DAT = Days after application of preemergence herbicides

Table 3. Effect of preemergence herbicides on grass cover crop species 28 days after treatment.

	Annual Ryegrass		Oat	
	Dry Weight	Emergence	Dry Weight	Emergence
	% reduction	no. of plants	% reduction	no. of plants
	First run			
EPTC	100	0	100	0
flumetsulam + metolachlor	100	0	39.1	4.5
metolachlor	100	0	54.8	4.5
pendimethalin	30.7	5.7	0	9.3
untreated	0	7.2	0	9.7
LSD (0.05)	18.6	1.1	25.9	1.5
	Second run			
EPTC	100	0.5	100	0.2
flumetsulam + metolachlor	100	0.3	40.3	5.5
metolachlor	100	0.5	41.6	7.3
pendimethalin	36.5	6.3	7.9	9.7
untreated	0	6.8	0	8.7
LSD (0.05)	17.5	1.1	14.5	1.1

Table 4. Effect of preemergence herbicides on legume cover crop species 28 days after treatment.

	Crimson Clover		Medium Red Clover	
	Dry Weight	Emergence	Dry Weight	Emergence
	% reduction	no. of plants	% reduction	no. of plants
	---------- First run ----------			
EPTC	18.9	7.8	0	6.7
flumetsulam + metolachlor	60.2	1.0	100	0
metolachlor	53.7	4.5	74.6	1.7
pendimethalin	23.6	7.2	30.3	5.7
untreated	0	7.8	0	8.5
LSD (0.05)	31.1	2.0	38.5	2.0
	---------- Second run ----------			
EPTC	47.1	7.5	0	3.3
flumetsulam + metolachlor	62.6	0.8	100	0
metolachlor	35.4	4.8	76.5	1.8
pendimethalin	6.5	7.7	0	4.7
untreated	0	5.2	0	5.5
LSD (0.05)	34.6	2.1	52.3	2.3

Table 5. Effect of postemergence herbicides on grass cover crop species 14 days after treatment.

	Annual Ryegrass		Oat	
	Dry Weight	Height	Dry Weight	Height
	% reduction	cm	% reduction	cm
	First run			
bentazon[a]	0	9.0	3.1	25.8
bromoxynil	28.2	10.5	0	28.3
dicamba	3.9	9.3	0	27.8
nicosulfuron[b]	91.3	3.8	85.6	9.0
primisulfuron[b]	92.2	4.0	84.5	8.8
2,4-D amine	0	10.0	0	23.8
untreated	0	9.0	0	24.5
LSD (0.05)	8.4	2.2	9.7	6.8
	Second run			
bentazon[a]	13.2	11.0	8.0	30.3
bromoxynil	42.1	12.8	15.9	30.3
dicamba	26.3	11.0	14.8	33.3
nicosulfuron[b]	94.7	6.3	75.0	20.0
primisulfuron[b]	76.3	9.3	77.3	17.8
2,4-D amine	18.4	15.8	10.2	30.8
untreated	0	13.8	0	31.3
LSD (0.05)	22.3	4.0	8.2	3.2

[a]included 1% v/v crop oil concentrate
[b]included 4% v/v 28% urea ammonium nitrate and 0.25% non-ionic surfactant

Table 6. Effect of postemergence herbicides on legume cover crop species 14 days after treatment.

	Crimson Clover		Medium Red Clover	
	Dry Weight	Height	Dry Weight	Height
	% reduction	cm	% reduction	cm
	First run			
bentazon[a]	32.1	8.0	23.6	11.6
bromoxynil	88.9	0.9	92.7	1.5
dicamba	77.8	0.6	89.1	1.0
nicosulfuron[b]	...	...	80	2.3
primisulfuron[b]	81.5	1.1	89.1	1.6
2,4-D amine	30.9	6.8	36.4	11.8
untreated	0	8.9	0	11.4
LSD (0.05)	16.6	1.0	12.6	1.0
	Second run			
bentazon[a]	60.0	6.8	20.8	11.0
bromoxynil	89.3	1.6	89.6	1.8
dicamba	77.3	1.5	79.2	2.8
nicosulfuron[b]	...	...	83.3	2.5
primisulfuron[b]	77.3	3.0	85.4	3.0
2,4-D amine	17.3	8.0	16.7	12.5
untreated	0	8.0	0	12.0
LSD (0.05)	15.3	1.1	17.0	1.3

[a]included 1% v/v crop oil concentrate

[b]included 4% v/v 28% urea ammonium nitrate and 0.25% non-ionic surfactant

Table 7. Effect of preemergence herbicides on annual ryegrass 30 days after various seeding times.

	Timing 1[a]			Timing 2			Timing 3			Timing 4		
	Injury	Density	Height	Injury	Density	Height	Injury	Density	Height	Injury	Density	Height
	%[b]	plants/ m row	cm	%	plants/ m row	cm	%	plants/ m row	cm	%	plants/ m row	cm
	1995											
EPTC	100	0	0	95.8	0	0	61.3	37.3	3.7	5.0	61.1	13.5
metolachlor	100	0	0	92.5	0	0	91.3	8.0	2.0	95.8	4.0	5.3
pendimethalin	85.0	10.8	9.0	82.5	4.5	8.2	65.0	34.9	4.2	42.5	37.4	7.1
untreated	...	43.3	11.2	...	21.5	6.1	...	71.1	6.7	...	69.4	15.2
LSD (0.05)	4.1	9.0	2.1	6.6	5.7	0.7	22.8	14.2	1.0	16.9	14.7	1.7
	1996											
EPTC	100	0	0	88.8	20.4	3.5	5.0	35.0	13.7	0	5.1	13.2
metolachlor	97.5	5.6	2.0	93.8	9.6	2.5	95.0	11.4	5.1	63.8	3.3	10.7
pendimethalin	84.5	12.9	5.1	43.8	33.5	7.3	58.8	25.5	10.4	15.0	9.4	13.4
untreated	...	48.3	10.9	...	45.3	12.6	...	32.3	13.9	...	5.8	13.1
LSD (0.05)	5.3	7.1	0.8	5.8	15.3	1.9	14.1	7.9	2.4	31.3	NS	NS

[a]Timings correspond to growth stage of corn grown adjacent to cover crops. Timing 1 = at planting; Timing 2 = V1-V2 corn; Timing 3 = V3-V4 corn; Timing 4 = V5-V6 corn.

[b]Injury visually evaluated in relation to the untreated plots

Table 8. Effect of preemergence herbicides on crimson clover 30 days after various seeding times.

	Timing 1[a]			Timing 2			Timing 3			Timing 4		
	Injury	Density	Height	Injury	Density	Height	Injury	Density	Height	Injury	Density	Height
	%[b]	plants/ m row	cm	%	plants/ m row	cm	%	plants/ m row	cm	%	plants/ m row	cm
	---- 1995 ----											
EPTC	53.8	18.5	2.8	67.5	9.6	3.3	3.8	17.9	3.9	0	14.5	6.5
metolachlor	71.3	16.3	2.2	42.5	12.3	4.1	3.8	17.6	3.3	15.0	12.5	5.4
pendimethalin	85.0	19.4	1.3	8.8	19.0	5.4	12.5	18.0	3.8	2.5	17.4	5.9
untreated	...	21.5	5.4	...	16.5	6.2	...	16.3	4.0	...	10.4	6.5
LSD (0.05)	7.2	NS	0.9	11.1	3.7	0.8	6.3	NS	NS	10.4	NS	0.7
	---- 1996 ----											
EPTC	80.5	13.6	2.8	40.0	19.8	3.7	2.5	19.5	8.4	0	5.6	5.6
metolachlor	60.0	12.3	2.5	57.5	19.1	3.4	16.3	15.0	6.8	5.0	9.0	5.1
pendimethalin	46.3	14.1	4.0	5.0	22.6	5.0	5.0	16.9	8.0	0	10.1	5.6
untreated	...	13.0	4.2	...	22.0	6.1	...	15.4	8.4	...	6.4	5.6
LSD (0.05)	29.9	NS	1.1	26.2	NS	1.3	NS	NS	1.1	NS	NS	NS

[a]Timings correspond to growth stage of corn grown adjacent to cover crops. Timing 1 = at planting; Timing 2 = V1-V2 corn; Timing 3 = V3-V4 corn; Timing 4 = V5-V6 corn.
[b]Injury visually evaluated in relation to the untreated plots