This is to certify that the

dissertation entitled

ANNUAL MEDICS: USE AS A COVER CROP IN CORN; WEED CONTROL; HERBICIDE TOLERANCE

presented by

John Meade Squire

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Crop and Soil Sciences

James J. Kells
Major professor

Date March 19, 1997

ANNUAL MEDICS: USE AS A COVER CROP IN CORN; WEED CONTROL; HERBICIDE TOLERANCE

By

John Meade Squire

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Sciences

1997

ABSTRACT

ANNUAL MEDICS: USE AS A COVER CROP IN CORN; WEED CONTROL; HERBICIDE TOLERANCE

By

John Squire

Annual medics (*Medicago* spp.) intercropped with corn offer another option to farmers who practice reduced input agriculture. Experiments with a two year cycle were conducted in a field corn system at East Lansing and Kellogg Biological Station, Michigan. Barrel medic (*M. truncatula* [L.] Gaertn.) and burr medic (*M. polymorpha* L.) were selected as intercrops to be seeded within the corn during the first year. For the second year of the cycle, monoculture corn was planted across the entire study and nitrogen fertilizer replacement values (N-FRV's) were estimated from treatments that were previously interseeded with annual medics. Using a range of N-FRV's and applying a price range of fertilizer N, medic seed+inoculum+planting breakeven costs (cost/acre for the system) were calculated. Corn grain yields were not reduced the first or second year of the cycle due to intercropping annual medics. Annual medics intercropped with corn failed to suppress weed growth. Annual medics intercropped with corn resulted in poor N-FRV's in monoculture corn the following season. Planting annual medics as an intercrop with corn to provide N to the following crop seems unfeasible.

The use of herbicides to control weeds in a corn/annual legume intercropping system is of concern because producers need to know which herbicides can be applied without seriously injuring the corn or the annual legume. Greenhouse trials evaluated soil and foliar applied herbicides on four legume species. Generally, the legumes tested in the greenhouse responded similarly to a given herbicide treatment. The one exception was that alfalfa (*M. sativa* L.) was more tolerant of bromoxynil than were the other three legumes in the study. Field studies evaluated the ability of berseem clover (*Trifolium alexandrinum* L.) and barrel medic to tolerate selected herbicides from greenhouse trials. Field studies indicated that EPTC, bentazon, and imazethapyr resulted in the least injury on berseem clover and barrel medic. Barrel medic tolerated 2,4-DB as well as it tolerated EPTC, bentazon, or imazethapyr. Conversely, berseem clover did not tolerate 2,4-DB applications as well as did barrel medic.

ACKNOWLEDGMENTS

I want to express my gratitude to those who helped, supported and encouraged me throughout my experience at Michigan State University. Thanks to Dr. Oran B. Hesterman who made it possible to come here to school and provided funding for a research project and guidance. I express my gratitude to Dr. James J. Kells for assuming guidance and for his counsel, help and opportunities he presented me throughout my program. Also, thanks to my other committee members, Dr. Richard R. Harwood and Dr. Scott W. Swinton for their support and help with this degree. I will reflect on the memories gained here for years to come.

I want to thank the faculty members and fellow graduate students who rendered their services to this project. I appreciate the help from Joe Paling, for the resource he was and the experience he provided. Thanks to Anil Shrestha who helped with many aspects of this project and the other graduate students of the forage project, John Fisk and Eric Spandl, who assisted. I am also thankfull for help from the Weed Science students and faculty who have helped in my research. I have gained many friendsips at MSU, in fellow students and faculty, and they will not be easily forgotten.

In a special way I want to thank my wife, Monique, for her support with school and other aspects of my life. Monique encouraged me to get a Ph.D., so I thank her for the moral support and help she has given. I also want to acknowledge my children who may wonder why their dad was gone so much. My family is, and will always be dear to me and I want them to know that.

PREFACE

Chapter 2 and chapter 3 of this dissertation are written as manuscripts in the style required for publication in the *Journal of Production Agriculture* and *Weed Technology*, respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

ANNUAL MEDICS: USE AS A COVER CROP IN CORN; WEED CONTROL; HERBICIDE TOLERANCE

INTRODUCTION

Interest in cover crops (crops grown specifically to provide ground cover, reduce erosion, and provide or extract soil nitrogen [N]) and intercrops (crops that serve the same general purpose of cover crops but are grown together with another crop) has increased over the past five to ten years. This is likely a combination of farmers becoming more aware of alternative cropping systems and concern about inputs used in crop production. Intercrops may be used to reduce erosion and lower input requirements such as fertilizers and pesticides. This research discusses various aspects of intercropping corn (*Zea mays* L.) with annual medics (*Medicago* spp.).

When considering annual medics as an intercrop, farmers will want to know the financial benefits before incorporating them to their systems. Ecological benefits of cover crops have been demonstrated (Scott et al., 1987; Singh et al., 1986; Lambert et al., 1987; McVay et al., 1989), but farmers are also interested in evidence that the system will provide financial returns. Presenting farmers with economic analyses of a corn annual medic intercropping system will provide the basis for rational decisions.

Weed suppression is another possible reason to use intercropping systems. If annual medics suppress weeds they will decrease the need for herbicides. However, if weed suppression does not occur then herbicide alternatives should be considered as a means to control weeds since cultivation would destroy the annual medics. There are several herbicides registered for use on alfalfa (*M. sativa*). Similarly, farmers should have a set of herbicides to choose from that can be safely applied to annual medics.

ANNUAL MEDICS

Annual medics are true annuals and are closely related to alfalfa. They are native to the Mediterranean region which typically has hot dry summers, mild wet winters, and about 250 to 760mm rainfall (Buddenhagen, 1990; Crawford, 1985). There are at least 35 annual medic species occurring throughout the world (Lesins and Lesins, 1979). Some authors recognize as many as 82 annual medic species depending on their criteria for classification (Crawford et al., 1989; Small, 1987).

BIOLOGY

Annual medics grow quickly and most species will complete their life cycle in 65 to 100 days (Bauchan et al., 1994). In their native habitat and in Australia, annual medics grow as winter annuals, where they germinate in the fall, grow during the winter, set seed and die in the spring (Crawford et al., 1989). When raised in the Midwestern U.S., annual medics are planted as spring annuals and complete their life cycle before the end of the summer. The plant is susceptible to freezing and will die following a killing frost (Bauchan and Sheaffer, 1994). Annual medics do not require vernalization to set seed even though they are winter annuals in their native habitat. In dry climates such as Australia and the Southwestern U.S., annual medics produce hard seeds which can regenerate and produce another crop the following season. When grown in the Midwest with adequate soil moisture, annual medics produce a few hard seeds which may volunteer the following season but can be controlled with cultivation (Bauchan and Sheaffer, 1994).

Annual medic growth habits range from prostrate to semi-erect to erect, depending on the species and environment. Burr medic (*M. polymorpha* 'Santiago') grows somewhat prostrate; whereas, barrel medic (*M. truncatula* 'Mogul') is a semi-erect variety. Even within a species there can be tremendous variation. For example, burr medic varies in characteristics such as pod appendages (spines), susceptibility to *Phytophthora* root rot, morphology, pest resistance, and cold tolerance (Barnes and DeHaan, 1994). This variation can be valuable for plant selection and breeding purposes.

Names of annual medics are often derived from pods produced by a species. Snail medic (*M. scutellata*) has pods that resemble a snail, burr medic is named for its spiney pods, and barrel medic has pods that resemble barrels. Seed size also differs among species with most medic seeds being larger than alfalfa seeds. Snail medic seed is about twice the size of barrel medic seeds which are a little larger than alfalfa seeds. Another feature that distinguishes annual medics from alfalfa is their method of pollination. Annual medics are self pollinated -do not require bees for seed production- and alfalfa is cross pollinated (Bauchan, and Sheaffer, 1994).

MANAGEMENT

The Australians have used annual medics in ley cropping systems to provide pastures for sheep since the 1950's. In the ley cropping system medics grow during the "off" year in rotation with small grains. Medics replaced the long fallow in the wheat (*Triticum eastivum* L.) fallow-rotation and provided pastures for grazing. Additionally, medics supplement N to the soils to enhance grain yield. The adoption of the wheat-medic pasture rotation has increased cereal production by up to 50% and doubled animal production (Lake, 1994).

In Australia medics are grazed during the winter and reseed naturally each season. In the "wheat-sheep" zone high levels of hard seed are produced with a typical medic cultivar. A thin waxy layer covers the seed and stops it from absorbing water. Over time the wax weathers and cracks with extended periods of high temperatures. About 10 to 20% of the total medic seedbank becomes pervious to water over a summer period to germinate in the autumn. This means that good legume pastures will continue up to five or more years after initial seed set (Lake, 1994).

Researchers have evaluated annual medic for their potential in cropping systems at various locations throughout the US (Bauchan and Sheaffer, 1994; Krall et al., 1996; Rumbaugh and Johnson, 1986; Sims and Slinkard, 1991; Brahim and Smith, 1993; Ocumpaugh, 1987). Sims and Slinkard (1991) adapted the Australian ley farming to the Montana small grain system, replacing the fallow period with various medics including black medic (*M. lupulina* L.). The first cycle of ley farming seemed encouraging but the second cycle was not. Black medic showed the most promise of any medics they tested to increase wheat yields. Barrel medic, strand medic (*M. littorali* L.), and snail medic came back poorly from seed produced the previous year (Sims and Slinkard 1991). Rumbaugh and Johnson (1986) evaluated 34 medic species and found *M. lupulina* to be most suited to conditions found in Northern Utah. One factor they mentioned was that black medic was the only species to produce abundant seedlings the second year following planting. Annual medic species evaluated in the study did not sufficiently regenerate from seed the following season.

USE AS A FORAGE

History has demonstrated that annual medics are adapted to grazing and its forage quality is comparable to that of alfalfa (Bauchan et al., 1994; Shrestha, 1996). Similar to alfalfa, annual medic can cause bloat in animals and should be introduced slowly or with grasses. Since annual medics can be used as a forage the question arises whether a farmer can justify raising a crop to cut for hay. Annual medics are planted in a similar method as alfalfa but must be inoculated with the correct *Rhizobium* strain as standard alfalfa inoculum may not be effective (Bauchan et al., 1994). Shrestha (1996) evaluated barrel medic compared to three other legume species (alfalfa, red clover [*Trifolium pratense* L.], and berseem clover *[Trifolium alexandrinum* L.]) in a cutting management study to determine yield and regrowth of the crops. Barrel medic (an annual) gave the lowest total dry matter yield (1.8 Mg/ha), had poor regrowth after cutting and no growth or reseeding the following spring. In a separate study, Shrestha (1996) demonstrated that barrel medic yielded up to two times more dry matter than burr or snail medic. He also indicated that barrel medic was more suited to grazing than to mechanical harvest.

USE OF ANNUAL MEDICS FOR INTERCROPPING WITH CORN

Annual medics have been and can be used in various cropping systems in the Midwest as spring annuals. They have been seeded into small grains, soybeans (*Glycine max* [L.] Merr.) seeded into asparagus (*Asparagus officinalis*), vegetable crops, and even sugar beets (*Beta vulgaris* L.). Intercropping annual medics with corn has been and is under investigation in Michigan for use in reduced input agriculture. The objective of the intercrop research is to develop a corn-annual legume intercropping system that farmers can feasibly adapt to their practices.

Annual legumes intercropped with corn would be preferred to perennial legumes in certain aspects. The mentioned annual legumes are relatively small when grown in the Midwest and therefore do not demand as much water as something like red clover. Also, since they are annuals, there is no need to desiccate the legumes before planting a crop the following season; whereas, biennial red clover must be killed and/or incorporated before planting another crop the following spring. Another reason to consider annual medics and berseem clover as intercrops is that they do not produce significant hard seed in the Midwest to volunteer and become a significant weed the next year (Bauchan and Sheaffer, 1994).

Medic planting date and interference in the corn is of concern. Since corn is the primary crop, efforts must be taken to ensure that corn grain yields are not reduced by any intercropping practice. Cropping practices which favor the interseeded crop often impair corn yields and practices which enhance corn production may negatively influence the intercrop (Nordquist and Wicks, 1974; Schaller and Larson, 1955). For example, the earlier a legume is interseeded after planting corn, the more likely corn yields will diminish (Pendleton et al., 1957; Jeranyama, 1995). Even though legumes fix N, nitrogen competition is of concern where it is deficient in the soil (Tomar et al., 1988).

If corn rows are widened to promote a legume intercrop, lower corn yields result when compared with corn monoculture planted with standard row spacing (Tesar, 1957; Jellum and Kuo, 1990). If planted later in the season to avoid interference with the corn, annual medics may not produce desirable biomass (Jeranyama, 1995). Jeranyama (1995) demonstrated that interplanting annual medic into corn about four weeks following corn planting resulted in acceptable corn yields. Farmers who apply these (annual medic intercropping) systems must do so using proper cultural practices to avoid yield reduction, or they must accept the trade-offs in corn grain yield or legume growth.

In a corn-annual medic intercropping system the annual medic is not mechanically harvested. There are at least two reasons for this: First, the annual medic grows so close to the soil surface that it is difficult to harvest (Shrestha, 1996), and second, corn stalks would interfere with harvesting the annual medic. Another reason that they are not mechanically harvested is that corn harvest is so late in the season that the medic may freeze and died before it can be harvested. Some farmers may graze livestock on land that had corn intercropped with annual medic.

ADVANTAGES TO INTERCROPPING

There are many advantages and disadvantages to intercropping annual medic with corn. When considering the alternatives of intercropping, a farmer must evaluate all the aspects. There are environmental, cultural/technical, and cost/return issues of intercropping that play a role in the final decision of whether or not to plant annual medic into corn. This portion of the paper will discuss ecological aspects (advantages and disadvantages) of intercropping.

Nitrogen Fixation. Many people include legumes in a cropping system because they fix N (Hesterman, 1988). In Australian ley farming annual medics are valued for N contribution to the following wheat crop. In fact the "organic" form (N in legume residues) may be desired over fertilizer N which frequently produces variable or even negative yields in drier years (Lake, 1994). Lake (1994) explained that this is likely because the rate and extent of N mineralization is dependent on soil moisture (which also relates to crop yield). Annual medics intercropped with corn have been reported to provide N Fertilizer Replacement Values (FRV) of 40 kg ha^{-1} on the following corn monoculture crop (Jeranyama, 1995).

Annual medics can supplement N fertilizers when grown as cover crops or intercrops and thereby decrease fertilizer N requirements. Since annual medics are relatively new to the U.S. there is little information available concerning their potential for N fixation. Research conducted in Minnesota reported N in aboveground biomass of three medic species intercropped with barley (*Hordeum vulgare* L.) ranging from 66 to 140 kg ha^{-1} (Moynihan et al., 1996). When intercropped with corn in Michigan some annual medics provided the equivalent of 40 kg ha^{-1} of N (Jeranyama, 1995).

Soil Stabilization. Altieri (1995) summarized many of the benefits of cover cropping practices. Systems that include legume intercrops may reduce soil erosion and fertilizer requirements to the following crop (Scott et al., 1987). Erosion is reduced because the intercrop increases ground cover which reduces the impact from rain and wind erosion. Also, additional roots from the intercrop help hold the soil in place and discourage erosion. Since annual medic is not mechanically harvested it remains on the soil surface even after corn harvest and into the winter if not incorporated. The intercrop may also improve water infiltration rather than overland flow or runoff (Lal et al., 1991; McVay et al., 1989).

Biodiversity and Organic Matter. Intercrops increase biological diversity and activity above and below ground (Singh et al., 1986). Diverse species such as corn and annual medic intercrop result in diverse crop residues. These residues promote diverse macro/micro fauna and flora that feed on the residues which results in diverse organic matter (OM) substrate. The resulting biodiversity provides a more stable source of nutrients to crops. This may be seen if one pool (perhaps species of residue/ OM) of nutrients cannot be accessed due to environmental conditions perhaps another pool can be. This insures nutrient availability and promotes a stable crop yield.

The addition and increase in OM from intercrops is also valuable in nutrient management, including water. Crop residues serve as an insulation when they cover the surface or they help buffer temperatures when they are incorporated. Residues also conserve soil moisture and may increase soil moisture holding capacity (Lal et al., 1991; Utomo et al., 1987; Frye et al., 1988). The residue and/or OM serves as a sink and a source for plant nutrients such as N, P, and K. Overall, intercrops/cover crops improve soil fertility, maintain OM, and recycle nutrients (Lal et al., 1991).

Insect and Pathogens. Another potential benefit from intercropping is that it creates a habitat for beneficial insects or the additional vegetation provides a barrier against predacious insects. Lambert et al. (1987) demonstrated reduced European corn borer damage when red clover was intercropped with corn, compared to monocropped corn in Ontario, Canada. They also reported that it was important to have planted the clover 10 days after planting the corn (Lambert et al. 1987). Intercrops also may provide a physical barrier that reduces the dispersal or production of spores from the soil and thereby discourage diseases emanating from the soil. Phatak et al. (1991) found differences among cover crops and their ability to control densities of various plant pathogen propagules. Some reduced the propagule densities while others had higher densities than the control.

Weed Suppression. Annual medics have potential to suppress weeds. Sheaffer and Barnes (1994) reported weed suppression from annual medics when intercropped with corn or soybeans, but they also reported crop yield reductions (likely because the medic was planted at the same time as the crop). They further stated that the intercropping success is influenced by the weed species and environmental conditions. It seems that when a legume is interplanted at the same time as corn chances of weed suppression are improved but corn yields are more likely to be reduced (Jeranyama, 1995; Sheaffer and Barnes, 1994). Conversely, if medic interplanting is delayed then weed suppression by medics may suffer.

There are inconsistent reports about cover crops (annual medic or other legumes) suppressing weeds. Some indicate they can be used to suppress weeds (Sheaffer and Barnes, 1994; Mt. Pleasant and Scott, 1991; Ilnicki and Vitolo, 1986) and others report poor or no weed suppression (Hartwig and Laughran, 1989; White et al., 1981). For instance, Robinson and Dunham (1954) reported ineffective weed control from either alfalfa or red clover intercropped with soybeans. Weed control was even a problem when alfalfa was planted into corn with 203 cm row spacing (Tesar, 1957). Exner and Cruse (1993) used EPTC pre-plant incorporated before planting corn and legumes. In this case, in those treatments where weeds were not controlled with secondary measures, reduced legume ground cover poor legume stands resulted. Townsend and Thomison (1996) reported inconsistent weed control from hairy vetch and red clover interseeded into corn at last cultivation.

DISADVANTAGES TO INTERCROPPING

Weed and Crop Suppression. Just as there are advantages to intercropping legumes with corn, there are disadvantages that one must consider. Much of the literature cites inconsistent or poor weed control when legumes are intercropped or grown as a cover crop (Robinson and Dunham, 1954; White et al., 1981; White, 1987; Tesar, 1957; Exner and Cruse, 1993;) Part of this may be due to diversity of weeds and their competitiveness. Additionally, medics may act as weeds in some respects. Intercropped legumes may interfere with crop yields if proper management is not followed (Jeranyama, 1995; Sheaffer and Barnes 1994).

Herbicide Alternatives. The use of intercrops in corn frequently restricts the herbicide alternatives available to a farmer. Without an intercrop one would only have to consider herbicides that can be safely applied to one crop, but with the intercrop, herbicide safety to both crops must be considered. Many researchers that have evaluated cover crops or intercrops have included a herbicide application, as a variable or a constant within the study (Hartwig and Loughran, 1989; Mt. Pleasant and Scott, 1991; Schultz et al., 1987; Ilnicki and Vitolo, 1986). With overwintering, cover crops farmers face the issue of desiccating the cover crop before planting the primary crop (Worsham and White, 1987; Wagger, 1989). If the cover crop does not naturally winter kill it must be plowed/disked into the soil or desiccated with a herbicide to facilitate crop growth.

Soil Moisture. Moisture depletion can be a disadvantage during dry periods or if the intercrop gets so large that it competes for moisture. If corn is planted into standing cover or a freshly desiccated legume cover crop, soil moisture depletion may limit production (Ebalhar et al., 1984; Frye et al. 1988; Badaruddin and Meyer, 1989; Wagger, 1989).

A farmer wishing to adopt intercropping annual legumes with corn needs to consider equipment adaptations. One way to adapt equipment to plant intercrops is to attach a seeding device to the cultivation equipment. The adjustments and money spent on adaptations, as well as learning planting methods, rates, timing, etc., are costs and/or disadvantages to intercropping. Also, seed availability and cost is a concern. The primary source of annual medic seed is from Australia and current U.S. supplies are limited.

METHODS OF DETERMINING N CONTRIBUTION

Legume N fixation may not directly represent the amount of N supplied to the following non legume crop. Part of the reason for this may be due to soil, plant, moisture, and microbial variation. Another explanation for this is what is termed the "rotation effect" which enhances yields but is not related to N (Baldock et al., 1981; Hesterman and Sheaffer, 1984; Russelle et al. 1987). Various experiments produced values for the rotation effect in corn of 5 to 10% greater yield in rotated vs. continuous corn (Higgs et al., 1976; Kurtz et al., 1984; Voss and Shrader, 1979).

There are at least three methods that can be used to quantify the amount of N contributed from a legume to a following nonlegume crop: 1) directly measure N content in the legume biomass; 2) calculate an N fertilizer replacement value for the legume using a following crop response; 3) use ^{15}N enriched legumes and measure the uptake of that ^{15}N by the following crop (Hesterman, 1988). These three methods combine both biologically fixed N and N in the plant tissue that was absorbed from the soil.

BIOMASS N

The legume biomass method relies on sampling a known area of biomass and measuring the total amount of N in the plant (shoot and root). With this quantified, the researcher can make the appropriate calculations to report N per unit area. This indicates the amount that could be incorporated and potentially become available to the following crop (Hesterman, 1988). There are limitations to this method in that not all of the plant N becomes available in one season. Studies have shown between 14 and

28% of the plant N is absorbed by a following crop (Ladd and Amato 1986; Ladd et al., 1983; Harris et al., 1994; Harris and Hesterman, 1987)

FERTILIZER REPLACEMENT VALUE METHOD

A nitrogen fertilizer replacement value can be defined as "the quantity of fertilizer N required to produce a yield in a crop that does not follow a legume that is identical to that produced by incorporation of the legume" (Hesterman, 1988). This could also apply to continuous corn compared with a corn/medic intercrop. An N-FRV is determined by deriving a response curve to N fertilization in a continuous crop, to which the response of a crop following a legume without N fertilizer is compared. This method assumes that the crop following the legume responds only to legume N (soil N is the same for both) and that legume residue N and fertilizer N are equally available (Hesterman, 1988). Hesterman et al. (1992) suggest that FRV comparisons be made only when there is a significant difference between the crop following a legume and one that was not proceeded by a legume.

NITROGEN ISOTOPE METHOD

The final, and most accurate method of determining legume N provided to the following crop is by using ^{15}N. With this method, the legume is fertilized with ^{15}N to prevent nodulation and enrich the plant with the isotope. The legume is then harvested and incorporated into the soil where a nonlegume crop will be planted. The nonlegume crop is harvested and analyzed for ^{15}N to quantify legume N uptake (Hesterman, 1988). Limitations of this method include: 1) the high cost of ^{15}N which limits the size of the experiment, 2) high cost of analyzing plant and soil samples for the isotope, and 3) mineralization and immobilization cycles can result in low apparent ^{15}N recovery rates (Jansson and Persson, 1982; Hesterman, 1988; Harris et al.,1994).

PROFITABILITY EVALUATIONS

If corn intercropped with annual medic will financially benefit farmers by reducing inputs or increasing returns they will be inclined to adopt these practices. Producers need information about costs and returns when deciding if they should employ intercropping. Intercropping practices can be valued by their ability to: suppress weeds, enhance yields by adding N, reduce pest damage, minimize erosion, or improve soil quality. Ideally, all of these factors should be included when valuing a corn-annual medic intercropping system. Unfortunately, it is very difficult to place a value on soil quality improvement, or erosion control to say nothing of measuring these parameters over a short period of time. The approach applied herein is to value intercropping based on its influence on yield measured by the N-FRV method.

Using the quantity of N fertilizer provided from the FRV (the NFRV) and the cost of the medic seed+planting a "breakeven" cost for fertilizer N can be calculated. Breakeven analysis provides a value which a producer would have to meet to be as well off with the new practice (the challenger) as with the old practice (the defender). The equation used to calculate the breakeven cost/acre for medic seed is:

Breakeven cost for medic seed+inoculum+planting = *NFRV* $acre^{-1}$ *x N price*

Similar analyses can be used to economically compare two cropping systems. Breakeven costs per area for challenger can be calculated when the farmer knows the Variable Costs (VC) of the challenger per area, the Return To Fixed Costs (RTFC) of the defender (gross revenue - VC) per area, and yield of the defender per area:

Breakeven price = (VC challenger + RTFC defender) / yield of the challenger.

The breakeven yield can be calculated when one knows VC challenger per area, RTFC defender per area, and price per volume or wt. of the challenger:

Breakeven yield = (VC challenger + RTFC defender) / price challenger

(Hilker et al., 1987).

Farmers who use breakeven analyses can construct a table of values which indicates the range of breakeven prices of a challenger, given a corresponding yield of the challenger. The table is useful in planning because it can exhibit possible outcomes or risks of a cropping system. Producers can use breakeven analyses and their derived tables as important decision making tools.

SUPPRESSION OF WEEDS WITH ANNUAL MEDICS

Since annual medics are being studied as an intercrop with corn and since weed control is a concern in the corn system, it is logical to investigate medic's potential to suppress weeds. As stated earlier, some researchers have reported annual medic suppression of weeds (Sheaffer and Barnes, 1994; Moynihan et al., 1996); however, their systems have not matched those discussed in this research. Therefore, the following discussion will review methods to study interference between species.

INTERFERENCE RESEARCH

There are four different methods of measuring weed interactions, each with its advantages and disadvantages (Radosevich, 1987). Numerous factors influence a plants ability to suppress another and it is often difficult to ascertain the cause of suppression. When it is unclear what factor(s) is responsible for one plant suppressing another then the term interference is used. Competition is reserved for use when the researcher knows what is causing the response. Therefore, the term competition is frequently used incorrectly (Schmenk, 1994).

In the additive design, two species are grown together and the density of one is held constant while the other is varied to evaluate the aggressive ability of the second (Radosevich and Holt, 1984). This design is commonly used in the field to test the effects of weed interference on a crop. The additive approach to studying weed interference is valuable in reporting the influence of a given weed density on crop yields, and in determining economic thresholds for weed control (Fausey, 1996).

The substitutive or replacement series design (deWitt, 1960; Harper, 1977) evaluates competitiveness between species and is based on the concept of density-independent yield (yield remains constant as density varies, within limits). This method holds total density (species A plus species B) constant and varies their proportions from 0 to 1.0. This method assesses the competitiveness of a species proportion at a constant total density. Yield ratios relate resource use and aggressiveness among species (Harper, 1977; Trenbath, 1978). Harper (1977) presented four possible interference models based on the outcome of competition between two species.

The third method of researching competition uses a systematic design. Nelder (1962) first used this model for spacing single species studies, but it has also been used for two species analyses. Interspecific effects can be evaluated by altering the position of two species along an arc or spoke to attain various proportions or ratios. The advantages of this method are: 1) that an array of densities can be studied without altering plant pattern arrangement, 2) only a small area is needed to study the effect of various densities, and 3) it allows flexibility with possible environmental gradients that may occur in the field. There are also disadvantages: 1) arcs may be difficult to place in the field along or between crop rows, 2) only individual plants can be measured, this confounds "stand" effect with association of neighbor plants, and 3) the effects of intraspecific competition cannot be readily separated from interspecific competition (Radosevich, 1987).

The neighborhood method of measuring interference focuses on plant yields based on their proximity to adjacent plants. In these designs, the "performance" of the target plant becomes a function of the number, biomass, cover, aggregation, or distance of its neighbors (Radosevich, 1988). Goldberg and Werner (1983) used this design to evaluate the effect of a target species over a range of densities of a neighboring species. Gunsolus and Coble (1986) used the method to evaluate influence of individual weeds on soybean productivity. However, the system reports yield responses pertaining only to individual crop plants and total crop yield must be extrapolated from individual plants (Radosevich, 1987).

HERBICIDE TOLERANCE IN ANNUAL MEDICS

Since annual medics are relatively new to the U.S. there is little known about their tolerance to herbicides. When farmers use annual medics for intercropping, they need to know what herbicides can be used without severely injuring the medic or associated crops. After researching a few legume cover crop systems in Alabama, Brown and Whitwell (1985) indicated that successful weed control should include herbicides such as paraquat or glyphosate plus fluometuron and possibly a residual herbicide.

When little information is available on crop tolerance to herbicides a screen is conducted. A screen is the application of various herbicides to a species to observe their response or tolerance to herbicides. Applying several classes of herbicides to various different medic species will provide insight as to which herbicides medics tolerate. In the case of sweet white lupin (*Lupinus alba* L.), little was known about their tolerance to herbicides, so Penner et al. (1993) tested various herbicides for safety to the plant. Since herbicide families have similar chemical properties (Renner and Kells, 1994; Gunsolus and Curran 1992), a selection from each family can provide a survey of herbicide tolerance.

There are several ways to classify herbicides including: 1) Timing of application, which refers to whether the chemical is applied preplant, preemergence, or postemergence. Some herbicides can be applied by more than one method which may cause confusion in its classification; 2) Herbicides can be classified by their chemical structure and properties, and; 3) Mode of action or the method by which they kill the plant. The seven major modes of action are: 1) growth regulators, 2) amino acid synthesis inhibitors, 3) lipid synthesis inhibitors, 4) seedling growth inhibitors, 5) photosynthesis inhibitors, 6) cell membrane disruptors, and 7) pigment inhibitors (Renner and Kells, 1994; Gunsolus and Curran 1992).

Timing of herbicide application is important for selectivity. For example a preplant incorporated herbicide may kill sprouting seedlings while a postemergence herbicide may only kill plants with foliage and presents no danger to germinating seeds. Some herbicides have both soil and foliar activity and one should be aware of the potential damage to each developmental stage. Herbicide selectivity is the reason bromoxynil (only foliarly active) can be applied to standing corn with annual medic being interseeded the same day. If a preplant incorporated or preemergence herbicide was applied at corn planting, and persisted until medic planting, it may kill the medic. Therefore, it is important to match the proper herbicide and application time to the desired cropping system.

LITERATURE CITED

Altieri, M.A. 1995. Agroecology: the science of sustainable agriculture. ch. 10. p. 219-232. Westview Press, Inc., Boulder, CO.

Badaruddin, M. and D.W. Meyer. 1989. Water use by legumes and its effects on soil water status. Crop Sci. 29:1212-1216.

Baldock, J.O., R.L. Higgs, W.H. Paulson, J.A. Jackobs, and W.D. Shrader. 1981. Legumes and mineral N effects on crop yield in several crop sequences in the upper Mississippi valley. Agron. J. 73:885-890.

Barnes, D.K. and R.L. DeHaan. 1994. Breeding *Medicago polymorpha* for Mid-West cropping systems. p.10. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Bauchan, G.R., N. Diwan, and M. McIntosh. 1994. What are annual medics? p.4. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Bauchan, G.R., and C.C. Sheaffer. 1994. Annual medics and their use in sustainable agriculture systems. p.1-3. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Brahim, K. and S.E. Smith. 1993. Annual medic establishment and the potential for stand persistence in southern Arizona. J. Range Manage. 46:21-25.

Brown, S.M., and T. Whitwell. 1985. Weed control programs for minimum tillage cotton (*Gossypium hirsutum*). Weed Sci. 33:843-847.

Buddenhagen, I.W. 1990. Legumes in farming systems in Mediterranean climates. p.3-29. *In* A.E. Osman et al. (eds.) Proc. of UNDP/ICARDA workshop. 20-24 June 1988, Tunis. Kluwer Academic Publishers. The Netherlands.

Crawford, E.J. 1985. Flowering response and centres of origin of annual Medicago species. *In* Z. Hochman (ed.) The Ecology and agronomy of annual medics. Proceedings of a workshop at the agricultural research and advisory station, Condobolin, Australia, 1981.

Crawford, E.J., A.W.H. Lake, and K.G. Boyce. 1989. Breeding annual *Medicago* species for semiarid conditions in souther Australia. Advances in Agronomy. 42:399-435.

deWitt, C.T. 1960. On Competition. Versl. Landbouwkd. Onderz. 66:1-82.

Ebalhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from cover crops for no-tillage corn. Agron. J. 76:51-55.

Exner, D.N. and R.M. Cruse. 1993. Interseeded forage legume potential as winter ground cover, nitrogen source, and competitor. J. Prod. Agric. 6:226-231.

Fausey, J. 1996. Competitiveness of giant foxtail (*Setaria faberi*) and fall panicum (*Panicum dichotomiflorum*). M.S. Thesis, Michigan State Univ., East Lansing, MI.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. p. 129-154. *In* W.L. Hargrove (ed.) Cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. 51. ASA, Madison, WI.

Goldberg, D.E. and P.A. Werner. 1983. Equivalence of competitors in plant communities: A null hypothesis and a field experimental approach. Am. J. Bot. 70(7):1098-1104. Harper, J.L. 1977. Population Biology of Plants. Academic Press, New York.

Gunsolus, J.L. and H.D. Coble. 1986. The area of influence approach to measuring weed interference effects on soybean. Abstr. Weed Sci. Soc. Am. p. 10.

Gunsolus, J.L. and W.S. Curran. 1992. Herbicide mode of action and injury symptoms. North Central Regional Ext. Publ. 377.

Harris, G.H., O.B. Hesterman, E.A. Paul, S.E. Peters, and R.R. Janke. 1994. Fate of legume and fertilizer nitrogen-15 in a long-term cropping systems experiment. Agron. J. 86:910-915.

Harris, G.H., and O.B. Hesterman. 1987. Recovery of nitrogen-15 from labeled alfalfa residue by a subsequent corn crop. p. 58-59. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Soil Conserv. Soc. Am., Athens, GA. 27-29 Apr. 1987. Soil Water Conserv. Soc. Am., Ankeny, IA.

Harper, J.L. 1977. Population biology of plants. Academic Press, New York. 892.

Hartwig, N.L., and J.C. Loughran. 1989. Contribution of crownvetch with and without tillage to redroot pigweed control in corn. Proc. Northeastern Weed Sci. Soc. 43:39-42.

Hesterman, O.B., T.S. Griffin, P.T. Williams, G.H. Harris, and D.R. Christenson. 1992. Forage legume-small grain intercrops: Nitrogen production and response of subsequent corn. J. Prod. Agric. 5:340-348.

Hesterman, O.B. 1988. Exploiting forage legumes for nitrogen contribution in cropping systems. p. 155-166. *In* W.L. Hargrove (ed.) Cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. 51. ASA, CSSA, and SSSA, Madison, WI.

Hesterman, O.B., and C.C. Sheaffer. 1984. Evaluation of N contributions and rotation effects in legume-corn sequences. p. 128. *In* Agron. abstracts. ASA, Madison, WI.

Higgs, R.L., W.H. Paulson, J.W. Pendleton, A.F. Peterson, J.A. Jackobs, and W.D. Shrader. 1976. Crop rotations and nitrogen: Crop sequence comparisons on soils of the driftless area of southwestern Wisconsin. 1967-1974. Univ. of Wisconsin College of Agric. and Life Sci. Res. Bull. R2761.

Hilker, J.H., J.R. Black, and O.B. Hesterman. 1987. Break-even analysis for comparing alternative crops. Extension bulletin E-2021. Michigan State Univ., East Lansing, MI.

Ilnicki, R.D., and D.B. Vitolo. 1986. The use of subterranean clover as a living mulch in corn. Proc. Northeastern Weed Sci. Soc. 40:36.

Jansson, S.L., and J. Persson. 1982. Mineralization and immobilization of soil nitrogen. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agronomy 22:229-252.

Jellum, E.J. and S. Kuo. 1990. Effects of corn row pattern and intercropping with legumes on silage corn. J. Prod. Agric. 3:545-551.

Jeranyama, P.J. 1995. Effect of planting date on dry matter yield and nitrogen accumulation of annual medic species either clear seeded or intercropped with corn. M.S. thesis. Michigan State Univ., East Lansing, MI.

Krall, J.M., R.H. Delaney, D.A. Claypool, and R.W. Groose. 1996. Evaluation of annual medicago Spp. for winter hardiness on the U.S. high plains. p. 178. *In* Agron. Abstracts. ASA, Madison, WI.

Kurtz, L.T., L.V. Boone, T.R. Peck, and R.G. Hoeft. 1984. Crop rotations for efficient nitrogen use. p 295-306. *In* R.D. Hauck (ed.) Nitrogen in crop production. ASA, CSSA, and SSSA, Madison, WI.

Ladd, J.N., and M. Amato. 1986. The fate of nitrogen from legume and fertilizer sources in soil successively cropped with wheat under field conditions. Soil Biol. Biochem. 18:417-425.

Ladd, J.N., M. Amato, R.B. Jackson, and J.H.A. Butler. 1983. Utilization by wheat crops of N from legume residues decomposing in soils in teh field. Soil Biol.

Biochem. 13:251-256.

Lake, A. 1994. Utilization of annual medics in Australia. p.8. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Lal. R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. p.1-11. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Soil Conserv. Soc. Am., Jackson, TN. 9-11 April 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Lambert, J.D.H., J.T. Arnason, A. Serratos, B.J.R. Philogene, and M.A. Faris. 1987. Role of intercropped red clover in inhibiting European corn borer (*Lepidoptera: Pyralidae*) damage to corn in eastern Ontario. J. Econ. Entomol. 80:1192-1196.

Lesins, K. and I. Lesins 1979. Genus *Medicago* (Leguminosae). A taxogenetic study. Junk, The Hague, Netherlands.

McVay, K.A., D.E. Radcliffe, and W.L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J. 53:1856-1862.

Moynihan, J.M., S.R. Simmons, and C.C. Sheaffer. 1996. Intercropping annual medic with conventional height and semidwarf barley grown for grain. Agron. J. 88:823-828.

Mt. Pleasant, J. and T.W. Scott. 1991. Weed management in corn polyculture systems. pp 151-152. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Soil Conserv. Soc. Am., Jackson, TN. 9-11 April 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Nelder, J. A. 1962. New kinds of systematic designs for spacing experiments. Biometrics. 18:283-3007.

Nordquist, P.T., and G.A. Wicks. 1974. Establishment methods for alfalfa in irrigated corn. Agron. J. 66:377-380.

Ocumpaugh, W.R. 1987. Annual medic evaluation for South Texas pasuters. p. 39-40. *In* N.P. Clarke (ed.) rorage research in Texas, 1987. Texas Agric. Exp. Stn. CPR-4537.

Pendleton, J.W., J.A. Jackobs, F.W. Slife, and H.P. Bateman. 1957. Establishing legumes in corn. Agron. J. 49:44-48.

Penner, D., R.H. Leep, R.C. Roggenbuck, and J.R. Lempke. 1993. Herbicide efficacy and tolerance in sweet white lupin. Weed Tech. 7:42-46.

Phatak, W.C., R.L. Bugg, D.R. Summer, J.D. Gay, K.E. Brunson, and R.B. Chalfant. 1991. Cover crop effects on weeds, diseases, and insects of vegetables. p. 153-154. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Soil Conserv. Soc. Am., Jackson, TN. 9-11 April 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Radosevich, S.R. 1988. Methods to study crop and weed interactions. p. 121-143. *In* M.A. Altier, and M.Z. Liebman (eds.) Weed management in agroecosystems: Ecological approaches. CRC Press Handbook. Boca Raton, FL.

Radosevich, S.R. 1987. Methods to study interactions among crops and weeds. Weed Technol. 1:190-198.

Radosevich, S.R. and Holt, J. 1984. Weed Ecology: Implications for Vegetation Management. J. Wiley and Sons, New York.

Renner, K.A. and J.J. Kells. 1994. Weed control guide for field crops. Mich. State Univ. Ext. Bull. E-434.

Robinson, R.G., and R.S. Dunham. 1954. Companion crops for weed control in soybeans. Agron. J. 46:278-281.

Rumbaugh, M.D., and D.A. Johnson. 1986. Annual medics and related species as reseeding legumes for Northern Utah pastures. J. Range. Manage. 39:52-58

Russelle, M.P., O.B. Hesterman, C.C. Sheaffer, and G.H. Heichel. 1987. Estimating nitrogen and rotation effects in legume-corn rotations. p. 41-41. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Natl. Conf., Athens, GA. 27-29 April. Soil Conserv. Soc. Am., Ankeny, IA.

Schaller, F.W. and W.E. Larson. 1955. Effect of wide spaced corn rows on corn yields and forage establishment. Agron. J. 47:271-275.

Schmenk, R.E. 1994. Velvetleaf (*Abutilon theophrasti* Medik.) competitiveness in corn as affected by preemergence herbicides. p.19. M.S. Thesis, Michigan State Univ., East Lansing, MI.

Schultz, M.A., A.E. Erickson, and J.A. Bronson. 1987. Intercropping corn and forage legumes in Michigan. p. 91-92. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Soil Conserv. Soc. Am., Athens, GA. 27-29 Apr. 1987. Soil Water Conserv. Soc. Am., Ankeny, IA.

Scott, T.W., J. Mt. Pleasant, R.F. Burt, and D.J. Otis. 1987. Contributions of ground cover, dry matter, and nitrogen from intercrops and covercrops in a corn polyculture system. Agron J. 79:792-798.

Sheaffer, C.C. and D.K. Barnes. 1994. Annual medics in Minnesota agriculture. p. 5. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Shrestha, A. 1996. Annual medics and berseem clover as emergency forages or green manure for canola. Ph.D. dissertation. Michigan State University.

Sims, J.R., and A.E. Slinkard. 1991. Development and evaluation of germplasm and cultivars of cover crops. p. 121-129. *In* W.L. Hargrove (ed.). Cover crops for clean water. Proc. Soil Conserv. Soc. Am. Jackson, TN. 9-11 Apr. 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Singh, N.B., P.P. Singh, and K.P.P. Nair. 1986. Effect of legume intercropping on enrichment of soil nitrogen, bacterial activity, and productivity of associated maize crops. Exp. Agric. 22(4):339-344.

Small, E. 1987. Generic changes in trifolieae subtribe trigonellinae. *In* C.H. Stirton (ed.) Advances in legume systematics, part 3. Royal Botanic Gardens, Kew, United Kingdom.

Tesar, M.B. 1957. Establishment of alfalfa in wide-row corn. Agron. J. 49:63-68.

Tomar, J.S., A.F. MacKensie, G.R. Hehuys, and I. Alli. 1988. Corn growth with foliar nitrogen, soil-applied nitrogen, and legume intercrops. Agron. J. 80:802-807.

Townsend, M.L. and P.R. Thomison. 1996. Interseeding cover crops into corn for increased fertility and weed suppression. p.121. *In* Agron. Abstracts. Madison, WI.

Trenbath, B.R. 1978. Models and interpretation of mixture experiments. p.145. *In* J.R. Wilson (ed.) Plant relations in pastures. C.S.I.R.

Utomo, M., R.L. Blevins, and W.W. Frye. 1987. Effect of legume cover crops and tillage on soil water, temperature, and organic matter. p. 5-6. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Soil Conserv. Soc. Am., Athens, GA. 27-29 Apr. 1987. Soil Water Conserv. Soc. Am., Ankeny, IA.

Voss, R.D., and W.D. Shrader. 1979. Crop rotations: Effect on yield and response to nitrogen. Iowa State Univ. Coop. Ext. Serv. PM-905.

Wagger, M.G. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J. 81:236-241.

White Jr., A.W., E.R. Beaty, and W.L. Tedders. 1981. Legumes as a source of nitrogen and effects of management practices on legumes in pecan orchards. Proc. S. E. Pecan Growers Assoc. 74:97-106.

White, R.H. 1987. Control of legume cover crops in no-till corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) and allelopathic potential of legume debris and aqueous extracts. M.S. Thesis. 110 p. Crop Sci. Dept. N.C. State Univ. Raleigh, NC.

Worsham, A.D., and R.H. White. 1987. Legume effects on weed control in conservation tillage. p. 113-119. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Soil Conserv. Soc. Am., Athens, GA. 27-29 Apr. 1987. Soil Water Conserv. Soc. Am., Ankeny, IA.

Chapter 2

USE OF ANNUAL MEDICS FOR INTERCROPPING WITH CORN TO PROVIDE NITROGEN AND SUPPRESS WEEDS

ABSTRACT

Annual medics (*Medicago* spp.) intercropped with corn offer another choice to farmers who practice reduced input agriculture. Experiments with a two year cycle were conducted in a field corn system at East Lansing and Kellogg Biological Station, Michigan. Barrel medic (*M. truncatula* [L.] Gaertn.) and burr medic (*M. polymorpha* L.) were selected as intercrops to be seeded within the corn the first year. Medics were interseeded between 30 in. corn rows four weeks following corn planting at 16 or 32 pure live seeds/ft^2. Monoculture corn was established as the control and used as the standard for comparison. Medic and weed dry matter production were sampled four times throughout the growing season during the first year of the cycle. The second year of the cycle, monoculture corn was planted across the entire study and nitrogen fertilizer replacement values (N-FRV's) were estimated from treatments that were previously interseeded with annual medics. Using a range of estimated N-FRV's and applying a price range of fertilizer N, medic seed+inoculum+planting breakeven prices (price/lb of medic seed) were calculated. Corn grain yields were not reduced the first or second year of the cycle due to intercropping annual medics. According to weed dry matter yields, annual medics intercropped with corn failed to suppress weed

production. Annual medics intercropped with corn resulted in low to no N-FRV's in monoculture corn the following season. The application of market N prices to observed N-FRV's resulted in a medic seed+inoculum+planting breakeven cost of less than half current cost of growing intercropped medics. Planting annual medics as an intercrop with corn to provide N to the following crop seems unatractive.

INTRODUCTION

Elevated interest in cover crops has prompted researchers to study the potential of cropping systems that include cover crops or intercrops. Cover crops are crops that are planted to provide ground cover, reduce erosion, and provide or extract soil N. For purposes of this paper, intercrops are crops that serve the same general purpose of cover crops but are grown together with another crop. This research discusses the potential of corn (*Zea mays* L.) - annual medic (*Medicago* spp.) intercropping systems.

Altieri (1995) summarized many biological benefits of cover cropping practices. Legume intercrops may reduce soil erosion and fertilizer requirements to the following crop (Scott et al., 1987). They may also improve water infiltration and slow overland flow or runoff (Lal et al., 1991). Intercrops increase biological diversity and activity above and below ground (Singh et al., 1986). They add organic matter (OM) which contributes to nutrient management. Residue and/or OM serves as a sink and a source for plant nutrients such as N, P, and K. Overall, intercrops/cover crops improve soil fertility, maintain OM and recycle nutrients (Lal et al., 1991).

Annual medics are true annuals and are native to the Mediterranean region which typically has hot dry summers, mild wet winters, and about 10 to 30 in. rainfall (Buddenhagen, 1990; Crawford, 1985). In their native habitat and in Australia, annual medics grow as winter annuals (Crawford et al., 1989). When raised in the Midwestern U.S., annual medics are planted as spring annuals and complete their life cycle before the end of the summer. In dry climates such as Australia and the Southwestern U.S., annual medics produce hard seeds which can regenerate and produce another crop the following season. When grown in the Midwest with adequate soil moisture, annual medics produce few hard seeds which may volunteer the following season but can be controlled with cultivation (Bauchan and Sheaffer, 1994).

Researchers have evaluated annual medics for their potential in cropping systems at various locations throughout the US (Bauchan and Sheaffer, 1994; Rumbaugh and Johnson, 1986; Sims and Slinkard, 1991; Ocumpaugh, 1987). Sims and Slinkard (1991) adapted the Australian ley farming to the Montana small grain system, replacing the fallow period with various medics. Rumbaugh and Johnson (1986) evaluated 34 medic species and found *M. lupulina* to be most suited to conditions found in Northern Utah.

Many people include legumes in a cropping system because they fix nitrogen (Hesterman, 1988). In Australia the organic form (N in legume residues) may be desired over fertilizer N which frequently produces variable or even negative yields in drier years (Lake, 1994). Lake (1994) explained that this is likely because the rate and extent of N mineralization is dependent on soil moisture.

Sheaffer and Barnes (1994) reported weed suppression from annual medics when intercropped with corn or soybeans, but they also reported accompanied crop yield reductions. There are inconsistent reports about cover crops (annual medic or other legumes) suppressing weeds. Some indicate they can be used to control weeds (Sheaffer and Barnes, 1994; Mt. Pleasant and Scott, 1991;) and others report poor or no weed suppression (Hartwig and Laughran, 1989; White et al., 1981). Much of the literature portrays inconsistent or poor weed control when legumes are intercropped or grown as a cover crop (Robinson and Dunham, 1954; Exner and Cruse, 1993; Moynihan et al., 1996) Part of this may be due to diversity of weeds and their competitiveness with other plant species. Since annual medics are being studied as an intercrop with corn and weed control is a concern in the system, it is logical to investigate medics' potential to suppress weeds.

The use of intercrops may restrict herbicide application alternatives because there are two crops to consider rather than one. Many researchers that have evaluated cover crops or intercrops have included herbicides in their studies (Hartwig and Loughran, 1989; Mt. Pleasant and Scott, 1991). With overwintering cover crops, farmers face the issue of removing or by some means killing the cover crop before planting the primary crop (Worsham and White, 1987).

Annual medics can supplement N fertilizers when grown as cover crops or intercrops and thereby decrease fertilizer N requirements. Since annual medics are relatively new to the U.S. there is little information available concerning their potential for N fixation. Research conducted in Minnesota reported N in aboveground biomass of three medic species intercropped with barley (*Hordeum vulgare* L.) ranging from 59 to 125 lb/acre (Moynihan et al., 1996). When intercropped with corn in Michigan some annual medics provided the equivalent of 36 lb N/acre (Jeranyama, 1995).

One method for estimating the amount of N provided by a legume is the N fertilizer replacement value (FRV) method. Hesterman (1988) outlines and reviews this technique for developing an N-FRV. Nitrogen fixation from legumes may not directly represent the amount of N supplied to the following non legume crop. This may be due to soil, plant, moisture, and microbial variation. Another explanation for this is what is termed the "rotation effect" which enhances yields but is not related to N (Russelle et al. 1987). The objectives of this research were to: (i) determine the response of corn to intercropped annual medics, (ii) examine the effect of intercropped annual medics on weeds, (iii) study the economics of corn intercropped with annual medics.

MATERIALS AND METHODS

Experiments were conducted at East Lansing and Kellogg Biological Station (KBS) near Hickory Corners, Michigan, from 1994 through 1996. Studies consisted of a two year cycle in which annual medics were intercropped with corn the first year and monoculture corn was raised the second year. Two complete cycles were evaluated at each location. Soil type at East Lansing, is a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) and at KBS is a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf).

FIRST YEAR OF THE CYCLE

Fields were spring moldboard plowed, disked, and/or field cultivated in preparation for the study. Nitrogen, was applied at 150 lb N/acre and P, and K were applied according to soil test recommendations. EPTC (Eradicane) was applied across all treatments at 4 lb ai/acre and incorporated to a depth between two and three in. before corn planting. The study was planted to corn (Pioneer hybrid 3751) at a target population of 26,000 seeds/acre, and a 30 in. row spacing. Corn was planted within the first two weeks of May, which is typical for this region of Michigan (Table 1). One month after corn planting, bromoxynil (one factor of the study) was applied at 0.375 lb ai/acre to appropriate plots. After bromoxynil was applied, the entire study was cultivated in preparation for medic interseeding. Annual medics were then seeded between the corn rows with a five-row nursery seeder, each row spaced 6 in. apart. Corn height at time of medic seeding ranged from 3 to 8 in. at KBS and from 5 to 16 in. at East Lansing (Table 1).

Measurements. Weeds and medics were sampled at 3, 6, 9, and 12 weeks following medic planting. A quadrat with approximate dimensions of 13 by 30 in. was centered over a corn row and samples were collected up to 15 in. on either side of the row. Plant materials were clipped at the soil surface, separated into medics or weeds, dried at 140° F for three days and weighed. Medic and weed weights are reported as lb/acre dry matter. When corn reached physiological maturity (black layer) a sample from each treatment was picked, shelled, dried, and weighed. Corn grain was adjusted to 15.5% moisture and reported as Bu/acre. The sample area for corn grain consisted of the two center rows of each plot and were 18 ft long.

SECOND YEAR OF THE CYCLE

Due to soil type and environmental conditions, the study area at East Lansing was fall plowed to incorporate corn stover and medic residues. At KBS (a coarser textured soil), the study area was spring plowed to avoid soil erosion. Phosphorus and potasium were applied according to soil test recommendations. Corn (Pioneer hybrid 3751) was planted at the same spacing and density as the first year to the same plot areas that existed in the first year of the study. Either chlorpyrifos [O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate], or fonofos [*O*-ethyl-s-phenylethylphosphonodithioate], was banded over the corn row at 1.5 lb ai/acre to control corn rootworms (*Diabrotica* spp.). Cyanazine plus metolachlor was applied at 1.75 plus 2 lb ai/acre, respectively, preemergence to the corn. Four rates of N (0, 60, 120, and 180 lb/acre) were applied to treatments that were not interseeded with medics the first year of the cycle. The remaining treatments did not receive supplemental fertilizer N.

Measurements. After physiological maturity, corn ears were picked from the same areas sampled the first year of the cycle. Corn grain yields were estimated using the same procedures as the first year and reported as Bu/acre at 15.5% moisture. Corn stover was measured from the same area in which grain was sampled. Stover samples were collected and dried at 140° F for at least 3 days, weighed and used to estimate stover dry matter yields. Subsamples of corn grain and stover were used for laboratory analyses to estimate N removed by the corn or stover from their respective treatments. Nitrogen in plant materials was measured according to the method described in Hach et al. (1987). The summation of N in the corn grain and corn stover from a given treatment was considered as the total N removed by the corn crop.

Fertilizer Replacement Value Determination. The first step in calculating the N-FRV was to develop a regression curve. The equation was based on total N removed by monoculture corn under four different N fertilizer rates (0, 60, 120, and 180 lb/acre). The second step was to compare total N removed by the corn following the annual medic intercrop with the fertilizer response curve. This was done by inserting the value of total N removed by corn following a medic intercrop into the regression equation and calculating the amount of fertilizer N required to produce the observed response. Even though regression analysis allows one to calculate all FRV's, they were only determined where a significant yield difference existed among treatments. Hesterman et al. (1992) also followed this logic in calculating FRV's of corn following small grains and legumes.

Economics. Economics were used to illustrate the value of this corn annual medic intercropping system. This system was valued only on the amount of fertilizer N equivalent contributed by annual medic intercropping. Economic analyses were used to compare a monoculture corn with a corn medic intercropping system. A table of values was constructed using a range of N-FRV's and a range of fertilizer N prices to determine a "breakeven cost" for medic seed plus inoculum plus planting costs. The following equation was used to calculate breakeven cost:

$$\text{Medic seed+inoculum+planting acre}^{-1} = \text{N-FRV acre}^{-1} \times \text{N price}$$

Breakeven value is that point where a producer would be just as well off with a new practice as with the current practice.

Design and Analysis. The research was an incomplete block design with four replications. The three factors of the experiment were: foliar applied herbicide, medic species, and medic planting rate. There were two levels of herbicide (with or without), three levels of species (none, 'Mogul' barrel medic [*Medicago truncatula* L.], and 'Santiago' burr medic [*M. polymorpha* L.]), and three levels of seeding rate (0, 16, and 32 pure live seeds [PLS]/ft^2). Analyses of variance were performed on data within year and location because significant interactions of year and location were detected. Significant differences were determined using an F-test and mean separations were performed using Fisher's Least Significant Difference (LSD) where the F-test indicated significance ($P \leq 0.05$).

RESULTS AND DISCUSSION

CORN GRAIN YIELD

Corn intercropped with annual medics demonstrated no significant grain yield reduction at either location or cycle (Table 2 and Table 3). Yield loss was of concern since research has indicated that corn yields can be reduced when annual medics are interseeded at the same time corn is planted (Sheaffer and Barnes, 1994; Jeranyama, 1995). The delay of interplanting medics four weeks following corn was likely the reason corn grain yield was not affected. Jeranyama (1995) also reported no corn yield loss when medic was interplanted four weeks after planting corn.

In the second year of the cycle (monoculture corn) there was no reduction in corn grain yield either. Conversely, there was no significant ($P \leq 0.05$) yield increase above the control (Tables 2 and 3) as might be predicted when medics were intercropped the year before. When selection criteria were relaxed ($P \leq 0.10$), there was one case at East Lansing where corn intercropped with Mogul in 1994 resulted in more corn grain in 1995 than the control (Table 2). A possible reason for no or poor yield response to medic intercropping is that there was insufficient annual medic (see Tables 4 and 5) to fix adequate N for the second year of corn. Another possible explanation is that the system was not in place long enough to acquire the appropriate microbial populations which facilitate nitrogen release (Smith, 1993).

MEDIC YIELD

When intercropped with corn, final medic dry matter yields in 1994 ranged from 80 lb/acre at the low seeding rate to 170 lb/acre at the high seeding rate (Table

4). In 1995, the interseeding at East Lansing senesced and died after 6 weeks (Table 5). In this case, medics did not establish very well before the corn canopy closed, and may have died due to lack of light. At KBS, in 1995, the interseeded medics grew well for at least nine weeks after planting and then senesced (Table 5). One might speculate that a dry period caused this reduction in 1995 compared to 1994, however, monthly precipitation for August and September was similar for these years. The most likely reason for medic yield reductions between 9 and 12 weeks after planting is that they completed their life cycle and degenerated. Medics are known to complete their life cycle in as little as 65 days (Bauchan and Sheaffer, 1994).

Generally, the higher medic seeding rate produced more dry matter within the first six to nine weeks. These trends did not hold true for the entire season as medic dry matter yields were similar, with the exception of KBS (1994), at the last two sampling periods (Tables 4 and 5). Dry matter yields in this study were consistent with data presented by Jeranyama (1995). He reported medic yields ranging from 200 to 460 lb/acre nine weeks after planting, and from 80 to 196 lb/acre 13 weeks after planting, under similar intercropping conditions. Moynihan et al. (1996) intercropped annual medics with barley in Minnesota and reported fall medic yields ranging from 1780 to over 5500 lb/acre. These yields may seem high in comparison to corn annual medic intercrops because medics barley and had time to grow after barley harvest.

WEED SUPPRESSION

Weed growth appeared unaffected by intercropping annual medics with corn. Statistical analyses indicated no difference ($P \leq 0.05$) in weed dry matter yields among treatments, within sampling time and location (Tables 6 and 7). Dominant weed species present at East Lansing were common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.). Dominant weed species at KBS were common lambsquarters, velvetleaf (*Abutilon theophrasti* Medik.), fall panicum (*Panicum dichotomiflorum* Michx.), and large crabgrass (*Digitaria sanguinalis* [L.] Scop.). Weed pressure was greater at KBS than at East Lansing as indicated by dry matter estimates in Tables 6 and 7. A second, separate study was conducted in a controlled environment to verify field observations. This study supported and verified field observations. The second study indicated that Mogul did not interfere with barnyardgrass (*Enchinochloa crus-galli* [L.] Beauv.), or common lambsquarters, and with one exception, did not interfere with redroot pigweed (Appendix A). When intercropped with corn, these two species of annual medics did not appear to reduce weed growth.

FERTILIZER REPLACEMENT VALUE

The N-FRV's from this experiment were not different among treatments ($P \leq 0.05$), however, at East Lansing in 1995, yield increases were observed when selection criteria were relaxed ($P \leq 0.10$) (Table 2). Since Mogul intercropped with corn at East Lansing, in 1994, resulted in increased corn grain yields the following year, an N-FRV was calculated. A fertilizer N response line and accompanying equation were derived from appropriate treatments and revealed a significant ($r^2=0.98$) linear effect on total N removed (Figure 1). Application of total N removed by corn following a corn/Mogul intercrop to the derived regression equation revealed an equivalent of 36 lb N/acre supplied by the intercrop. No N-FRV's were calculated when corn grain yields were not different from the control.

Table 8 can be used to illustrate the range of breakeven medic planting costs given fertilizer N prices and the quantity of N fixed by the intercrop. Calculations demonstrated that, based on N alone, a producer would be financially better off purchasing fertilizer N than using annual medic intercrops as a nitrogen source. With an N-FRV of 36 lb/acre and fertilizer N prices of \$0.20, a farmer would have to purchase the medic seed and interplant it for less than \$7.20/acre to be as well off as purchasing fertilizer N (Table 8). Current annual medic seed prices range between \$14 and \$21 per acre at the low seeding rate (16 PLS/ft^2). Producers would also need to add planting costs when considering this type of system which range from \$10 to \$11 per acre (Doane's Agricular Report, 1996).

SUMMARY

One of the first concerns with intercropping annual medic with corn was reducing yields. Compromising corn grain yields can be feasible if returns in some other aspect of the system compensates for the reduction. Since intercropped medics are not mechanically harvested to provide additional income from the system, it was a concern that corn yields remain similar to standard practices. Intercropping annual medics with corn did not decrease corn yields compared to the control. Conversely, the use of medics as a preceding intercrop with corn did not result in a significantly ($P \leq 0.05$) higher corn grain yield the following season.

This research revealed no weed suppression by Mogul or Santiago medic. A separate greenhouse study supported field observations and illustrated the inability of Mogul to suppress barnyardgrass, common lambsquarters, and redroot pigweed. Poor weed suppression by medics and their failure to produce significant N-FRV's are factors which make this system unatractive. Calculations, based on equivalent N added to a following crop, demonstrated that intercropping annual medics with corn did not produce positive net returns using current nitrogen and medic seed prices.

LITERATURE CITED

Altieri, M.A. 1995. Agroecology: the science of sustainable agriculture. ch. 10. p. 219-232. Westview Press, Inc., Boulder, CO.

Bauchan, G.R., and C.C. Sheaffer. 1994. Annual medics and their use in sustainable agriculture systems. p.1-3. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Buddenhagen, I.W. 1990. Legumes in farming systems in Mediterranean climates. p.3-29. *In* A.E. Osman et al. (eds.) Proc. of UNDP/ICARDA workshop. 20-24 June 1988, Tunis. Kluwer Academic Publishers. The Netherlands.

Crawford, E.J., A.W.H. Lake, and K.G. Boyce. 1989. Breeding annual *Medicago* species for semiarid conditions in souther Australia. Advances in Agronomy. 42:399-435.

Crawford, E.J. 1985. Flowering response and centres of origin of annual Medicago species. *In* Z. Hochman (ed.) The Ecology and agronomy of annual medics. Proceedings of a workshop at the agricultural research and advisory station, Condobolin, Australia, 1981.

Doane's Agricultural Report. 1996. Estimated machinery operating costs, 1996. Vol. 59. No. 22. 5-8.

Exner, D.N. and R.M. Cruse. 1993. Interseeded forage legume potential as winter ground cover, nitrogen source, and competitor. J. Prod. Agric. 6:226-231.

Hach, C.C., B.K. Bowden, A.B. Kopelove, and S.V. Brayton. 1987. More powerful peroxide Kjeldahl digestion method. J. Assoc. Off. Anal. Chem. Vol 70 No. 5 pp. 783-787.

Hartwig, N.L., and J.C. Loughran. 1989. Contribution of crownvetch with and without tillage to redroot pigweed control in corn. Proc. Northeastern Weed Sci. Soc. 43:39-42.

Hesterman, O.B., T.S. Griffin, P.T. Williams, G.H. Harris, and D.R. Christenson. 1992. Forage legume-small grain intercrops: nitrogen production and response of subsequent corn. J. Prod. Agric. 5:340-348.

Hesterman, O.B. 1988. Exploiting forage legumes for nitrogen contribution in cropping systems. p. 155-166. *In* W.L. Hargrove (ed.) Cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. 51. ASA, CSSA, and SSSA, Madison, WI.

Jeranyama, P.J. 1995. Effect of planting date on dry matter yield and nitrogen accumulation of annual medic species either clear seeded or intercropped with corn. M.S. thesis. Michigan State Univ., East Lansing, MI.

Lake, A. 1994. Utilization of annual medics in Australia. p.8. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Lal. R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. p.1-11. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Soil Conserv. Soc. Am., Jackson, TN. 9-11 April 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Moynihan, J.M., S.R. Simmons, and C.C. Sheaffer. 1996. Intercropping annual medic with conventional height and semidwarf barley grown for grain. Agron. J. 88:823-828.

Mt. Pleasant, J. and T.W. Scott. 1991. Weed management in corn polyculture systems. pp 151-152. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Soil Conserv. Soc. Am., Jackson, TN. 9-11 April 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Ocumpaugh, W.R. 1987. Annual medic evaluation for South Texas pasuters. p. 39-40. *In* N.P. Clarke (ed.) rorage research in Texas, 1987. Texas Agric. Exp. Stn. CPR-4537.

Robinson, R.G., and R.S. Dunham. 1954. Companion crops for weed control in soybeans. Agron. J. 46:278-281.

Rumbaugh, M.D., and D.A. Johnson. 1986. Annual medics and related species as reseeding legumes for Northern Utah pastures. J. Range. Manage. 39:52-58

Russelle, M.P., O.B. Hesterman, C.C. Sheaffer, and G.H. Heichel. 1987. Estimating nitrogen and rotation effects in legume-corn rotations. p. 41-41. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Natl. Conf., Athens, GA. 27-29 April. Soil Conserv. Soc. Am., Ankeny, IA.

Scott, T.W., J. Mt. Pleasant, R.F. Burt, and D.J. Otis. 1987. Contributions of ground cover, dry matter, and nitrogen from intercrops and covercrops in a corn polyculture system. Agron J. 79:792-798.

Sheaffer, C.C. and D.K. Barnes. 1994. Annual medics in Minnesota agriculture. p. 5. *In* G.R. Bauchan (Workshop Organizer) Annual medics: Pre-conference workshop of the 34th North American alfalfa improvement conference.

Sims, J.R., and A.E. Slinkard. 1991. Development and evaluation of germplasm and cultivars of cover crops. p. 121-129. *In* W.L. Hargrove (ed.). Cover crops for clean water. Proc. Soil Conserv. Soc. Am. Jackson, TN. 9-11 Apr. 1991. Soil and Water Conserv. Soc. Ankeny, Iowa.

Singh, N.B., P.P. Singh, and K.P.P. Nair. 1986. Effect of legume intercropping on enrichment of soil nitrogen, bacterial activity, and productivity of associated maize crops. Exp. Agric. 22(4):339-344.

Smith, J.L. 1993. Cycling of nitrogen through microbial activity. p. 91-119. In J.L. Hatfield and B.A. Stewart (eds.) Soil biology: Effects on soil quality. Advances in Soil Science. Lewis Publishers.

White Jr., A.W., E.R. Beaty, and W.L. Tedders. 1981. Legumes as a source of nitrogen and effects of management practices on legumes in pecan orchards. Proc. S. E. Pecan Growers Assoc. 74:97-106.

Worsham, A.D., and R.H. White. 1987. Legume effects on weed control in conservation tillage. p. 113-119. *In* J.F. Power (ed.) The role of legumes in conservation tillage systems. Proc. Soil Conserv. Soc. Am., Athens, GA. 27-29 Apr. 1987. Soil Water Conserv. Soc. Am., Ankeny, IA.

Table 1. Conditions present during the year of corn/annual medic intercropping at East Lansing and Kellogg Biological Station (KBS).

	East Lansing		KBS	
	1994	1995	1994	1995
Corn planting date	May 13	May 11	May 4	May 8
Medic planting date	June 17	June 7	June 6	June 6
Corn height (in.) at medic seeding	9 to 16	5 to 9	3 to 7	5 to 8
Summer rainfall (in.)				
May	1.8	2.5	1.6	2.9
June	7.3	1.7	6.9	3.6
July	4.8	4.0	6.3	3.3
Aug.	5.6	4.6	4.7	4.3
Sept.	4.7	1.3	1.2	1.9

Table 2. Corn grain yields from the first cycle of intercropping annual medics with corn. Means are combined over medic planting rate for the year of the intercrop (1994) and the year following (1995). The entire study was fertilized with 150 lbs N/acre in 1994 and only the control plots were fertilized with listed N rates in 1995.

	East Lansing		KBS	
	1994	1995	1994	1995
Species	Intercrop	No intercrop	Intercrop	No intercrop
	Bushel/acre			
Mogul	196	111	182	104
Santiago	186	95	186	98
Control (0N)	172	84	186	102
Control (60N)†	189	134	199	130
Control (120N)†	191	143	206	149
Control (180N)†	190	162	201	145
$LSD_{(0.05)}$	n.s.	n.s.	n.s.	n.s.
$LSD_{(0.10)}$	n.s.	17	n.s.	n.s.

† Valid comparisons can be made between Mogul, Santiago, and the control (0N) within a column. Treatment means for the other controls are given to indicate response to N.

Table 3. Corn grain yields from the second cycle of intercropping annual medics with corn. Means are combined over medic planting rate for the year of the intercrop (1995) and the year following (1996). The entire study was fertilized with 150 lbs N/acre in 1995 and only the control plots were fertilized with listed N rates in 1996.

	East Lansing		KBS	
Species	1995 Intercrop	1996 No intercrop	1995 Intercrop	1996 No intercrop
	Bushel/acre			
Mogul	177	165	134	110
Santiago	179	145	138	109
Control	182	163	134	99
Control (60N)†	181	167	141	99
Control (120N)†	181	149	164	100
Control (180N)†	198	176	142	73
$LSD_{(0.05)}$	n.s.	n.s.	n.s.	n.s.
$LSD_{(0.10)}$	n.s.	n.s.	n.s.	n.s.

† Valid comparisons can be made between Mogul, Santiago, and the control (0N) within a column. Treatment means for the other controls are given to indicate response to N.

Table 4. Medic dry matter yields from the first cycle of intercropping annual medics with corn (1994). Data are combined over species within a planting rate.

Weeks after planting Medics	East Lansing Density† 16	East Lansing Density† 32	KBS Density† 16	KBS Density† 32
	lb/acre			
3	12a‡	26b	9a	10a
6	33a	87b	51a	105b
9	66a	115b	37a	103b
12	54a	91a	37a	91b
15	136a	165a	80a	170b

† Medics were planted at 16 or 32 pure live seeds per square foot.

‡ Means followed by the same letter within a location and row are not significantly different (P≤0.05).

Table 5. Medic dry matter yields from the second cycle of intercropping annual medics with corn (1995). Data are combined over species within a planting rate.

Weeks after planting	East Lansing		KBS	
	Density†		Density†	
Medics	16	32	16	32
	lb/acre			
3	5a‡	12b	12a	26b
6	49a	97b	190a	330b
9	10a	19a	253a	318a
12	3a	2a	103a	109a
16	2a	2a	93a	81a

† Medics were planted at 16 or 32 pure live seeds per square foot.

‡ Means followed by the same letter within a location and row are not significantly different ($P \leq 0.05$).

Table 6. Weed dry matter yields from the first year of the first cycle of intercropping annual medics with corn (1994). Means are combined over medic planting rates.

Weeks after planting Medics	East Lansing Intercrop Mogul	East Lansing Intercrop Santiago	East Lansing Control		KBS Intercrop Mogul	KBS Intercrop Santiago	KBS Control	
	lb/acre							
3	64	34	58	n.s.†	13	22	29	n.s.
6	96	30	48	n.s.	151	98	62	n.s.
9	69	67	54	n.s.	246	326	374	n.s.
12	74	73	61	n.s.	344	395	201	n.s.

† n.s.= not significant ($P \leq 0.05$). Appropriate comparisons can be made within a location and row.

Table 7. Weed dry matter yields from the first year of the second intercropping cycle of annual medics with corn (1995). Means are combined over medic planting rates.

Weeks after planting Medics	East Lansing Intercrop Mogul	East Lansing Intercrop Santiago	East Lansing Control		KBS Intercrop Mogul	KBS Intercrop Santiago	KBS Control	
	lb/acre							
3	65	21	38	n.s.†	9	8	6	n.s.
6	176	74	88	n.s.	119	117	183	n.s.
9	200	79	84	n.s.	380	588	307	n.s.
12	139	91	61	n.s.	428	444	465	n.s.

† n.s.= not significant ($P \leq 0.05$). Appropriate comparisons can be made within a location and row.

Table 8. Breakeven cost/acre of Mogul seed+inoculum+planting based on Fertilizer N prices and N supplied from corn-medic intercropping.

Nitrogen Price	N-FRV† (lbs/acre)									
	20	25	30	35	40	45	50	55	60	65
($/lb)	Breakeven Cost‡									
0.10	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50
0.12	2.40	3.00	3.60	4.20	4.80	5.40	6.00	6.60	7.20	7.80
0.14	2.80	3.50	4.20	4.90	5.60	6.30	7.00	7.70	8.40	9.10
0.16	3.20	4.00	4.80	5.60	6.40	7.20	8.00	8.80	9.60	10.40
0.18	3.60	4.50	5.40	6.30	7.20	8.10	9.00	9.90	10.80	11.70
0.20	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00
0.22	4.40	5.50	6.60	7.70	8.80	9.90	11.00	12.10	13.20	14.30
0.24	4.80	6.00	7.20	8.40	9.60	10.80	12.00	13.20	14.40	15.60
0.26	5.20	6.50	7.80	9.10	10.40	11.70	13.00	14.30	15.60	16.90
0.28	5.60	7.00	8.40	9.80	11.20	12.60	14.00	15.40	16.80	18.20
0.30	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00	19.50

† N-FRV = nitrogen fertilizer replacement value.

‡ Cost/acre for Mogul seed+inoculum+planting

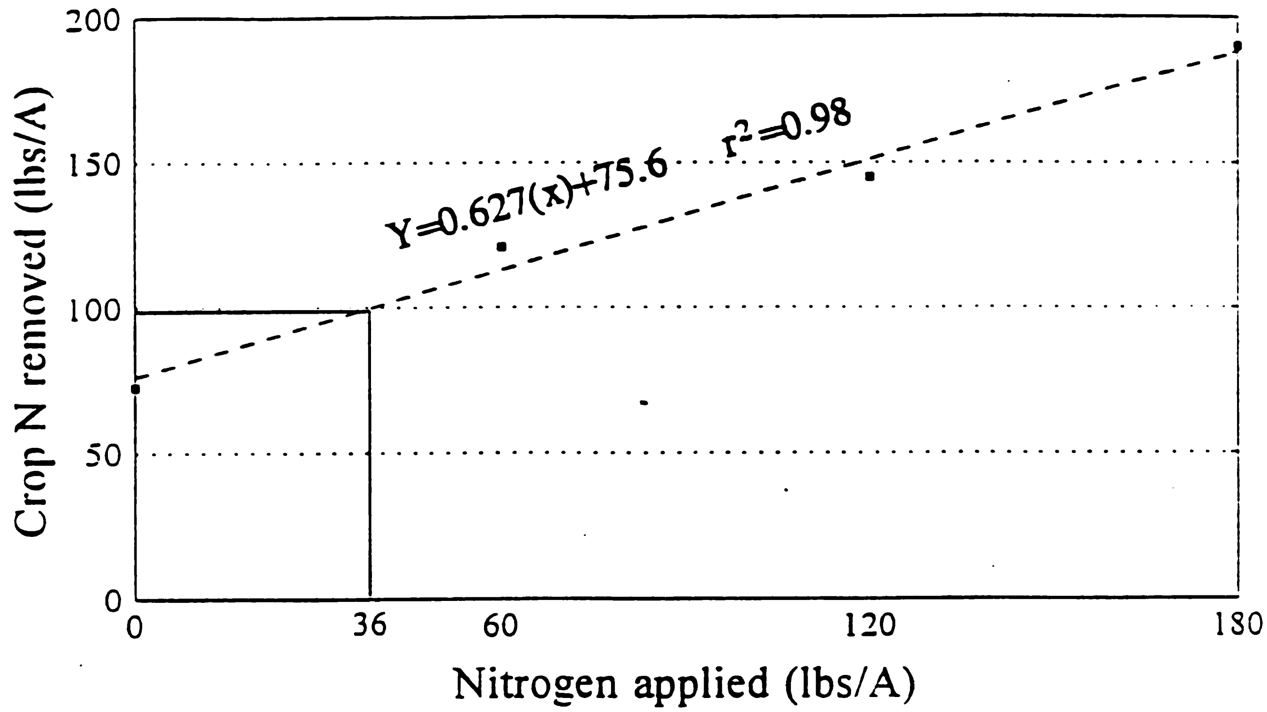

Figure 1. Regression line and equation used to derive the N-FRV of Mogul intercropped with corn at East Lansing, 1994. Y=total N removed by corn following the intercrop and X = the amount of N fertilizer required for a given crop response.

CHAPTER 3

HERBICIDE TOLERANCE IN FOUR LEGUME SPECIES

Abstract. The use of herbicides to control weeds in a corn/annual legume intercropping system is of concern since producers need to know what herbicides can be applied without seriously injuring the corn or the legume. Greenhouse trials on alfalfa, berseem clover, 'Mogul' barrel medic, and 'Santiago' burr medic identified EPTC, metolachlor, and pendimethalin for further testing on berseem clover and Mogul under field conditions. Of the POST herbicides tested in the greenhouse, bentazon, imazethapyr, MCPA, and 2,4-DB were also tested under field conditions on berseem clover and Mogul medic. Bromoxynil severely injured berseem clover, Mogul and Santiago medic, but did not injure alfalfa. EPTC, bentazon, and imazethapyr resulted in the least injury to berseem clover and Mogul under field conditions. Mogul medic also tolerated 2,4-DB. Berseem clover did not tolerate 2,4-DB as well as Mogul medic.

Nomenclature: bentazon, 3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide; bromoxynil, 3,5,-dibromo-4-hydroxybenzonitrile; 2,4-DB, 4-(2,4-dichlorophenoxy)butanoic acid; EPTC, S-ethyl dipropyl carbamothioate; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; MCPA, (4-chloro-2-methylphenoxy)acetic acid; metolachlor, 2-chloro-N-[2-ethyl-6-methylphenyl]-N-[2-methoxy-1-methylethyl] acetamide; pendimethalin, N-[1-ethylpropyl]-3,4-dimethyl-2,6-dinitrobenzenamine; alfalfa, *Medicago sativa* L.; 'Mogul' barrel medic, *Medicago truncatula* Gaertn.; berseem clover, *Trifolium alexandrinum* L.; 'Santiago' burr medic *Medicago polymorpha* L.

Additional index words. alfalfa, 'Mogul' barrel medic, berseem clover, 'Santiago' burr medic.

INTRODUCTION

Annual medics (*Medicago* spp.) have been evaluated for their potential as intercrops with corn and barley (Moynihan et al., 1996; Squire et al., 1997). Berseem clover (*Trifolium alexandrinum* L.) is another annual legume which has been intercropped with corn in some parts of mid Michigan. These clovers are relatively new to the mid-West and both originated in the Mediterranean region (Baldridge et al., 1992; Crawford, 1985).

One reason for intercropping these annual legumes with corn is to assist in weed control. Researchers have documented the value of weed control in corn systems and they have indicated the periods corn is sensitive to interference from weeds (Hall et al., 1992; Knake and Slife, 1969). If annual clovers intercropped with corn suppress weeds then they may provide an alternative method of weed control. Conversely, if berseem clover or annual medics do not suppress weeds then perhaps integrating herbicides to control weeds should be investigated. After researching a few legume cover crop systems in Alabama, Brown and Whitwell (1985) indicated that successful weed control programs should include herbicides such as paraquat (1,1'-dimethyl-4,4'-bypyridinium ion) or glyphosate (N-[phosphonomethyl]glycine) plus fluometuron (N,N-dimethyl-N'-[3-(trifluoromethyl) phenyl]urea) and possibly a residual herbicide.

If producers choose to intercrop annual legumes with corn and want to maintain corn yields, they will likely need to know what herbicides can be applied to both the corn and annual legumes without critically injuring either crop. Since annual medics are relatively new to the U.S. there is little known about their ability to tolerate herbicides. Therefore, research concerning herbicide tolerance in annual medics was necessary to assist in the proper management and decision making of corn-annual legume intercropping systems.

In a corn-annual legume intercropping system the legume is interplanted approximately four weeks following corn planting. Therefore a herbicide that is only foliarly active could be applied to control existing weeds before interseeding the legume. Such means of selectivity are useful before planting the legume, however, information on the sensitivity of these annual legume intercrops to PPI, PRE, and POST herbicides are not well documented. The objectives of this study were to evaluate herbicide tolerance in four legume species in a controlled environment and herbicide tolerance in two annual legumes in the field.

MATERIALS AND METHODS

GREENHOUSE SOIL APPLIED HERBICIDE STUDY

Alfalfa (*Medicago sativa* L.) was selected as a standard species for comparison in the greenhouse. Reasoning for this was that some herbicides labeled for use on alfalfa may be equally safe on annual medics. Berseem clover, 'Mogul' barrel medic (*M. truncatula* Gaertn.), and 'Santiago' burr medic (*M. polymorpha* L.) were the annual legumes selected for herbicide testing in the greenhouse. The four legume species were inoculated with appropriate *Rhizobium* spp. and planted 8 seeds per 946-ml plastic pot containing a sandy loam soil. PPI herbicides were applied to the soil and incorporated to approximately 5 cm before planting the seeds. PRE herbicide treatments were applied immediately after seeding the legumes. Herbicides were applied at one or two times the recommended label rate for corn. Table 1 reports the herbicides and corresponding application rates used for PPI and PRE treatments. Control pots used for comparison received no herbicide application. All herbicides were applied with a moving nozzle sprayer which delivered 234 L ha^{-1} and a spray pressure of 207 kPa. Pots were placed in a greenhouse with an ambient temperature of 25 ± 5 C and a 16-h photoperiod of natural plus supplemental lighting. Natural plus sodium vapor lighting provided a midday average of 1000 $\mu E\ m^{-2}\ s^{-1}$ in the greenhouse.

Twenty-eight days after herbicide application the number of living plants and dry matter yields of the four legume species were measured. Plant height was also measured at this time but data are reported in Appendix B. Treatments were replicated four times and organized in a randomized block design. Means from run 1 and 2 are reported separately due to significant treatment by run interactions. Plant numbers and dry matter yields are reported relative to the control. In cases where herbicide treated legumes weighed more or were more numerous than the control, the given treatment value was set equal to the control to facilitate arcsine transformations. This was considered acceptable since primary interest was on injury, not enhanced growth. Means from the transformed data were separated by LSD ($P \leq 0.05$) following analysis of variance. Significant differences observed in the analyses of transformed data were applied to corresponding relative number of living plants and relative dry matter yields.

GREENHOUSE FOLIAR APPLIED HERBICIDE STUDY

Berseem clover, alfalfa, Mogul, or Santiago seeds were inoculated with *Rhizobium* spp. and planted in 946-ml plastic pots containing a sandy loam soil. After emergence and before spraying, plants were thinned to four per pot. Herbicide treatments were applied at the second trifoliate leaf stage. Herbicides were applied with a moving nozzle sprayer that delivered 234 L ha^{-1} with a spray pressure of 207 kPa. A list of herbicides used and their corresponding application rates can be reviewed in Table 1. Plants were raised in a greenhouse with a temperature of 25 ± 5 C with a 16-h photoperiod of natural plus supplemental sodium vapor lighting, which provided a midday average of 1000 $\mu E\ m^{-2}\ s^{-1}$.

Plants were harvested 28 d after POST herbicide applications and mean dry matter weights were determined for each legume/herbicide combination (Plant heights were also measured at that time and data are presented in Appendix B). Treatments were replicated four times within a run and organized in a randomized block design. Means from run 1 and 2 are reported separately due to significant treatment by run interactions. Plant dry matters are reported relative to the control. In cases where herbicide treated legumes measured more than the control they were set equal to the control to allow arcsine transformations. Transformed data were statistically analyzed and means were separated by LSD ($P \leq 0.05$) methods. Resulting significant differences from the transformed data were applied to relative dry matter means from a given treatment.

FIELD STUDIES

In 1995 and 1996 field studies were conducted near East Lansing, MI, to evaluate herbicide tolerance in berseem clover and Mogul medic. The soil type in the field for 1995 was a Kibbie loam (fine-loamy, mixed, mesic Aquollic Hapludalfs) and in 1996 was a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs). Berseem clover and Mogul medic were planted at a target density of 39 pure live seeds m^{-2} in a split block fashion with four replications. EPTC [S-ethyl dipropyl carbamothioate] was applied PPI, whereas, metolachlor [2-chloro-N-[2-ethyl-6-methylphenyl]-N-[2-methoxy-1-methylethyl] acetamide], and pendimethalin [N-[1-ethylpropyl]-3,4-dimethyl-2,6-dinitrobenzenamine] were applied PRE immediately following legume planting. All herbicide applications were made with a tractor mounted compressed air plot sprayer that delivered 187 L ha^{-1} at a pressure of 207 kPa. POST herbicide treatments were applied at the second trifoliate leaf stage. Herbicides and respective rates used in field studies are listed in Table 1.

Plant height and percent injury were measured two and four weeks after foliar herbicide application and reported relative to the control. Dry matter yields were not measured due to weed interference and a low Mogul growth habit. By the fourth week after foliar herbicide applications, injury was less than the two week observations. Therefore, only data from the two week evaluation period are reported in this text (later measurements and comparisons are reported in Appendix B). Due to treatment by year interactions, treatment means from 1995 and 1996 are reported separately. Means were separated by LSD ($P \leq 0.05$) following analysis of variance. Significant differences encountered in the transformed data were applied to relative treatment means and reported in this paper.

RESULTS AND DISCUSSION

GREENHOUSE SOIL APPLIED HERBICIDE STUDY

Table 2 reports number of living plants and dry weights of alfalfa for PPI or PRE applied herbicides under greenhouse conditions. EPTC generally caused the least injury of any soil applied herbicide in terms of number of living plants or dry weights. These results concur with Dawson's (1983) report (in field trials) where alfalfa seedling emergence from 2 cm deep was not inhibited by any EPTC rate up to 243 kg ha^{-1}. Unlike EPTC in the present study, metolachlor and pendimethalin applications resulted in moderate to severe reduction in plant number and dry weight. Cyanazine resulted in complete mortality of the alfalfa.

Berseem clover tolerated EPTC better than it tolerated any other soil applied herbicide (Table 3). Berseem injury was expressed as reduced growth from metolachlor or pendimethalin applications rather than stand loss. Generally, the 2x rate of metolachlor or pendimethalin resulted in greater injury to berseem (plant number and dry matter) than the 1x rate of the same herbicides. Berseem did not tolerate either rate of cyanazine as plants treated with this herbicide died.

Mogul demonstrated tolerance of the 2x rate of EPTC as shown by plant numbers and dry weights which were similar to the untreated control (Table 4). With the 1x rate of metolachlor, dry weights ranged between 59 to 70% of the untreated. Since these dry weights were similar to dry weights where EPTC was applied, metolachlor was further tested under field conditions. Injury caused by pendimethalin was inconsistent between runs. Mogul dry weights ranged from 30 to 60% of the untreated in the first run and from 0 to 6% of the untreated in the second run. Therefore, pendimethalin was also studied in field trials. Both rates of cyanazine were lethal to Mogul medic.

Santiago plant numbers were somewhat consistent between EPTC, metolachlor, and pendimethalin within a run (Table 5). Alternatively, dry weights indicated that Santiago responded similarly to EPTC or pendimethalin, whereas, metolachlor resulted in low dry matter accumulation compared to EPTC treatments. As with the other three species, Santiago did not tolerate cyanazine.

Generally, EPTC did not reduce seedling emergence, and only slightly reduced growth of these four legumes when compared to the untreated. This indicates that EPTC has the most promise for use in a corn/annual legume intercropping system of any PPI or PRE herbicide tested in this study. Plant dry weight comparisons suggest that berseem and Santiago are more susceptible to metolachlor than were alfalfa or Mogul (Appendix B.3.). Due to variable injury from metolachlor or pendimethalin these herbicides were tested again under field conditions. No legume in this study tolerated cyanazine [2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile]. Without exception, when cyanazine was applied, legumes which germinated and emerged, died in the early stages of development.

GREENHOUSE FOLIAR APPLIED HERBICIDE STUDY

Generally, the herbicides tested did not injure (reduce dry matter weights) alfalfa more than 30% in the first run (Table 6). The second run revealed relatively severe injury from the 2x rate of bentazon [3-(1-methylethyl)-(1H)-2,1,3-

benzothiadiazin-4(3H)-one 2,2-dioxide] and both rates of nicosulfuron [2[[[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide] and primisulfuron [2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl] amino]sulfonyl]benzoic acid]. Injury from imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] was not different from the untreated control (run 2). This concurs with Wilson's (1994) report of no height or density differences between alfalfa treated with imazethapyr at 70 g ai/ha and untreated alfalfa.

Berseem produced similar dry matters when bentazon, imazethapyr, MCPA [(4-chloro-2-methylphenoxy)acetic acid], and 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid] were applied (Table 6). Injury from nicosulfuron and primisulfuron applications were inconsistent between runs. However, nicosulfuron and primisulfuron applications resulted in berseem dry weight reduction by as much as 50% in the second run. Bromoxynil [3,5,-dibromo-4-hydroxybenzonitrile] usually produced severe injury to berseem clover.

In run 1, Mogul treated with imazethapyr, MCPA, 2,4-DB, nicosulfuron and primisulfuron produced dry matters of about 70% or more of the untreated (Table 6). In the second run, bentazon, imazethapyr, MCPA, 2,4-DB, and nicosulfuron showed promise for safe use on Mogul. They resulted in 17 to 50% dry matter reduction compared to the untreated. Mogul was seriously injured by bromoxynil in both runs and by primisulfuron in the second run.

Generally, Santiago was injured less than 28% by imazethapyr, MCPA, 2,4-DB, and nicosulfuron in both runs (Table 6). These same herbicides were among the best choices (resulted in low injury) for application to the other species in this study. As with berseem and Mogul, Santiago was severely injured by bromoxynil. Santiago dry matter production was reduced by about half when bentazon was applied under greenhouse conditions in this study.

With the exception of bromoxynil, these four legumes responded similarly to any given herbicide in this study (Table 6). Analyses revealed that where bromoxynil was applied, (except the 1x rate to berseem clover in run 2) berseem, Mogul, and Santiago all produced less dry matter than alfalfa. Generally, the annual legumes were seriously injured if not killed by bromoxynil, whereas, alfalfa did not express such symptoms. Peters and Lowance (1972) reported no reduction in alfalfa or medium red clover (*T. pratense* L.) yields when treated with bromoxynil. Since bromoxynil is labeled for use on alfalfa, and Peters and Lowance (1972) reported that medium red clover also tolerated bromoxynil, one might predict similar tolerance in these annual *Trifolium* and *Medicago* species. The present research suggests that berseem responds differently than red clover (both *Trifolium* spp) when bromoxynil is applied POST and Mogul or Santiago responds differently than alfalfa to bromoxynil.

FIELD STUDIES

Visual injury as well as height measurements revealed very little damage to berseem clover from EPTC, bentazon, or imazethapyr (Table 7). Berseem was injured 42 to 76% by 2,4-DB and exhibited the classic twisting or epinastic response common to the phenoxy herbicides. Height measurements also indicated 2,4-DB injury compared to the untreated. Berseem clover showed inconsistent tolerance of MCPA between years with less injury occurring in the second year. Even with low injury the second year one may be skeptical about the safety of MCPA for use on corn/berseem intercrops. Metolachlor and pendimethalin applications caused more injury than would be tolerated in a production system (between 80 and 100% injury).

Mogul medic generally demonstrated little injury from applications of EPTC, bentazon, imazethapyr, or 2,4-DB in these field trials (Table 7). Conversely, mogul was severely injured by MCPA in both visual and height estimates. Similar to berseem, metolachlor and pendimethalin applications resulted in severe damage to Mogul.

Berseem and Mogul differed in their tolerance of metolachlor and pendimethalin (Table 7), however, this was of little concern because injury was so great to both species. Alternatively, differences in tolerance of 2,4-DB or MCPA between berseem and Mogul were of interest in this study due to low injury observed from some treatments. Comparisons of visual injury between berseem and Mogul indicated that berseem was more sensitive to 2,4-DB than was Mogul. Mogul was injured by a maximum of 20% by 2,4-DB, whereas, berseem was injured between 42 and 76%. Conversely, Mogul was injured more by MCPA than was berseem clover. The second year of testing MCPA on berseem indicated 9 to 32% injury from the herbicide. Further testing should be conducted to further understand and clarify berseem's ability to tolerate MCPA.

This research has indicated the potential of several herbicides for use in a corn annual legume intercropping system. Among those herbicides tested in both greenhouse and field conditions EPTC, bentazon, and imazethapyr revealed the greatest potential for use in this cropping system. 2,4-DB could likely be used on Mogul medic but may cause higher than acceptable injury to berseem clover in such an intercrop. One key finding was that alfalfa tolerated bromoxynil, whereas, berseem, Mogul and Santiago did not. If a producer desired to use bromoxynil for such an intercropping system the herbicide should be applied before interplanting the legume.

ACKNOWLEDGMENT

This work was supported in part by the USDA, Agreement 92-COOP-1-7266 and the North Central Region Sustainable Agric. Res. and Education Program. Any opinions, findings, conclusions or recommendations expressed herein are those of Michigan State University and do not necessarily reflect the views of the USDA.

LITERATURE CITED

Baldridge, D., R. Dunn, R. Ditterline, J. Sims, L. Welty, D. Wichman, M. Westcott, and G. Stallknecht. 1992. Berseem clover: A potential hay and green manure crop for Montana. Montguide, January 1992. Montana State Univ. Coop. Ext. Serv., Bozeman, MT.

Brown, S.M., and T. Whitwell. 1985. Weed control programs for minimum tillage cotton (*Gossypium hirsutum*). Weed Sci. 33:843-847.

Crawford, E.J. 1985. Flowering response and centres of origin of annual Medicago species. *In* Z. Hochman (ed.) The Ecology and agronomy of annual medics. Proceedings of a workshop at the agricultural research and advisory station, Condobolin, Australia, 1981.

Dawson, J.H. 1983. Tolerance of alfalfa (*Medicago sativa*) to EPTC. Weed Sci. 31:103-108

Hall, M.R., C.J. Swanton, and G.W. Anderson. 1992. The critical period of weed control in grain corn (*Zea mays*). Weed Sci. 40:441-447.

Knake, E.L. and F.W. Slife. 1969. Effect of time of giant foxtail removal from corn and soybeans. Weed Sci. 17:281-283.

Moynihan, J.M., S.R. Simmons, and C.C. Sheaffer. 1996. Intercropping annual medic with conventional height and semidwarf barley grown for grain. Agron. J. 88:823-828.

Peters, E.J. and S.A. Lowance. 1972. Bromoxynil, chloroxynil, and 2,4-DB for establishing alfalfa and medium red clover. Weed Sci. 20:140-142

Squire, J.M., J.J. Kells, O.B. Hesterman, C.C. Sheaffer, A. Shrestha, J.W. Fisk. 1997. Use of annual medics for intercropping with corn to provide nitrogen and suppress weeds. J. Prod. Agric. In review.

Wilson, R.G. 1994. Effect of imazethapyr on legumes and the effect of legumes on weeds. Weed Tech. 8:536-540.

Table 1. List of herbicides and corresponding rates used in greenhouse and field studies.

Herbicide	1x rate	2x rate
	---------- kg a.i. ha^{-1}	---------
Cyanazine†	1.68	3.36
EPTC	4.48	8.96
Metolachlor	2.24	4.48
Pendimethalin	1.68	3.36
Bentazon	0.84	1.68
Bromoxynil†	0.28	0.56
Imazethapyr	0.035	0.071
MCPA	0.21	0.42
2,4-DB	1.12	2.24
Nicosulfuron†	0.035	0.07
Primisulfuron†	0.04	0.08

† These herbicides were only used in greenhouse trials.

Table 2. Number of alfalfa plants present and dry matter weights four weeks after planting in greenhouse trials.

Herbicide/rate	Plant Number run 1	Plant Number run 2	Dry Weight run 1	Dry Weight run 2
	-- % of untreated --		-- % of untreated --	
EPTC 1x	86 ab†	100 a	71 b	76 bc
EPTC 2x	74 ab	88 ab	48 bcd	79 b
Metolachlor 1x	54 bc	64 bc	35 bcd	42 de
Metolachlor 2x	53 cd	48 cd	33 cd	25 def
Pendimethalin 1x	74 abc	63 bc	60 bc	41 cd
Pendimethalin 2x	60 bc	21 de	48 bc	6 ef
Cyanazine 1x	0 d	0 e	0 d	0 f
Cyanazine 2x	0 d	0 e	0 d	0 f
Untreated	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single.

Table 3. Number of berseem clover plants present and dry matter weights four weeks after planting in greenhouse trials.

Herbicide/rate	Plant Number run 1	Plant Number run 2	Dry Weight run 1	Dry Weight run 2
	-- % of untreated --		-- % of untreated --	
EPTC 1x	60 cd†	100 a	49 bc	97 ab
EPTC 2x	90 b	100 a	62 b	87 b
Metolachlor 1x	34 de	78 b	20 d	36 c
Metolachlor 2x	25 ef	10 d	12 de	2 d
Pendimethalin 1x	63 c	55 bc	38 c	25 cd
Pendimethalin 2x	29 ef	39 cd	7 de	13 cd
Cyanazine 1x	0 f	0 d	0 e	0 d
Cyanazine 2x	0 f	0 d	0 e	0 d
Untreated	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single column.

Table 4. Number of Mogul plants present and dry matter weights four weeks after planting in greenhouse trials.

Herbicide/rate	Plant Number run 1	Plant Number run 2	Dry Weight run 1	Dry Weight run 2
	-- % of untreated --		-- % of untreated --	
EPTC 1x	72 bc†	56 bc	81 ab	65 b
EPTC 2x	92 ab	100 a	100 a	100 a
Metolachlor 1x	70 abc	65 b	69 bc	59 bc
Metolachlor 2x	56 bc	48 bc	48 cde	30 cd
Pendimethalin 1x	61 bc	14 cd	60 bcd	6 d
Pendimethalin 2x	51 bc	0 d	33 de	0 d
Cyanazine 1x	0 d	0 d	0 e	0 d
Cyanazine 2x	0 d	0 d	0 e	0 d
Untreated	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single column.

Table 5. Number of Santiago plants present and dry matter weights four weeks after planting in greenhouse trials.

Herbicide/rate	Plant Number run 1	Plant Number run 2	Dry Weight run 1	Dry Weight run 2
	-- % of untreated --		-- % of untreated --	
EPTC 1x	89 a†	88 ab	53 b	64 bc
EPTC 2x	85 a	90 ab	44 b	78 ab
Metolachlor 1x	86 a	56 bc	28 c	32 cde
Metolachlor 2x	29 bc	45 cd	9 de	17 de
Pendimethalin 1x	96 a	75 abc	55 b	51 bcd
Pendimethalin 2x	53 b	80 abc	21 cd	44 bcd
Cyanazine 1x	0 c	0 d	0 e	0 e
Cyanazine 2x	0 c	0 d	0 e	0 e
Untreated	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single column.

Table 6. Legume dry matters harvested four weeks after herbicide application in greenhouse trials.

Herbicide/rate	Alfalfa run 1	Alfalfa run 2	Berseem run 1	Berseem run 2	Mogul run 1	Mogul run 2	Santiago run 1	Santiago run 2
	% of untreated							
Bentazon 1x	75 cd†	89 abc	75 bcd	75 abcdef	40 fg	73 b	51 def	73 bcd
Bentazon 2x	63 d	29 f	55 d	86 abcd	47 ef	62 bcd	47 ef	29 fg
Bromoxynil 1x	96 abc	64 cdef	10 e	56 def	11 gh	6 e	16 fg	2 g
Bromoxynil 2x	92 abc	77 bcd	7 e	5 g	0 h	0 e	0 f	1 g
Imazethapyr 1x	84 abcd	83 abc	84 abc	78 abcdef	81 cd	69 b	83 bc	93 ab
Imazethapyr 2x	70 cd	90 ab	72 cd	98 ab	67 cde	50 bcde	61 cde	91 abc
MCPA 1x	89 abc	74 bcd	70 cd	71 bcdef	72 cd	58 bcd	84 bc	92 abc
MCPA 2x	80 abcd	72 bcde	79 bc	75 bcdef	60 def	58 bcd	73 bcd	73 cd
2,4-DB 1x	92 abc	93 ab	92 ab	95 abc	68 cde	66 bc	84 bc	90 abc
2,4-DB 2x	95 abc	96 ab	84 bc	87 abcd	83 bc	67 bc	84 ab	84 bc
Nicosulfuron 1x	83 abcd	59 cdef	80 bcd	64 def	79 c	70 bc	82 b	74 bcd
Nicosulfuron 2x	81 bcd	56 def	82 bcd	43 fg	73 cd	55 bcd	79 bc	79 bc
Primisulfuron 1x	98 ab	47 ef	79 bc	59 cdef	78 cd	34 cde	89 ab	59 de
Primisulfuron 2x	94 abc	32 f	82 abc	49 fg	93 ab	19 de	87 ab	47 ef
Untreated	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single column.

Table 7. Legume visual injury and height evaluated two weeks after foliar herbicide applications in field trials near East Lansing, MI.

	Injury					
	Berseem		Mogul		Ber. vs Mog.	
Herbicide/rate	1995	1996	1995	1996	1995	1996
	%					
EPTC 1x	13 a†	1 a	11 a	3 a	NS‡	NS
EPTC 2x	21 a	4 ab	14 a	1 a	NS	NS
Bentazon 1x	15 a	1 a	20 abc	3 a	NS	NS
Bentazon 2x	15 a	13 b	40 bc	15 b	*	NS
Imazethapyr 1x	10 a	2 a	9 a	0 a	NS	NS
Imazethapyr 2x	9 a	1 a	13 a	3 a	NS	NS
2,4-DB 1x	46 b	42 d	14 a	6 ab	**	***
2,4-DB 2x	76 cd	55 e	19 ab	9 ab	***	***
MCPA 1x	49 b	9 ab	66 de	70 c	*	***
MCPA 2x	59 bc	32 c	81 ef	86 e	*	***
Metolachlor 1x	80 d	96 f	38 b	78 d	***	***
Metolachlor 2x	95 e	98 g	63 d	95 f	***	NS
Pendimethalin 1x	97 ef	98 g	86 f	86 e	*	***
Pendimethalin 2x	99 f	100 h	96 g	99 g	NS	*
	Height					
	% of untreated					
EPTC 1x	92 bc†	90 bcd	93 abc	87 bc	NS‡	NS
EPTC 2x	87 cd	87 cde	90 bc	83 bc	NS	NS
Bentazon 1x	97 ab	94 abc	84 cd	79 cde	*	*
Bentazon 2x	87 cd	93 bcd	79 de	68 def	*	**
Imazethapyr 1x	98 ab	97 ab	96 ab	81 cd	NS	NS
Imazethapyr 2x	95 abc	95 ab	92 abc	89 bc	NS	NS
2,4-DB 1x	88 cd	80 de	99 ab	93 a	*	NS
2,4-DB 2x	77 de	78 de	84 cd	79 cd	NS	NS
MCPA 1x	75 de	84 de	56 f	48 g	NS	**
MCPA 2x	64 ef	72 e	31 g	33 g	*	**
Metolachlor 1x	65 ef	47 f	85 cd	60 efg	*	NS
Metolachlor 2x	38 fg	43 f	76 def	51 fg	*	NS
Pendimethalin 1x	34 g	57 f	64 ef	54 g	*	NS
Pendimethalin 2x	0 h	0 g	27 g	49 g	NS	**

† Means followed by the same letter are not significantly different ($P \leq 0.05$). Acceptable comparisons can be made within a single column and response variable.
‡ Appropriate comparisons can be made between species within a given row and year. NS, *, **, *** represent nonsignificant, or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

APPENDIX A

REPLACEMENT SERIES STUDY

INTRODUCTION

Interest in annual medics as an intercrop and its suggested potential to suppress weeds prompted this research in a controlled environment. A field study that evaluated weed growth in a corn/annual medic intercropping system demonstrated no weed suppression. Therefore this greenhouse replacement series study was instigated to support the data and conclusions from the corn/annual medic intercropping system. The replacement series study evaluates the ability of one species to interfere with the growth of another.

MATERIALS AND METHODS

Barnyardgrass (*Enchinochloa crus-galli*), common lambsquarters (*Chenopodium album*), or redroot pigweed (*Amaranthus retroflexus*) seeds were planted in various ratios with 'Mogul' burr medic (*Medicago truncatula*). This was carried out by planting and later thinning combinations of weeds and medics in pots to a ratio of 100:0, 75:25, 50:50, 25:75, 0:100. Pot size was approximately 5 in. deep, with a 6 in. diameter. Seeds were planted equidistantly in BACCTO[2] greenhouse potting soil and watered as needed throughout the study. A fungicide was applied after planting to reduce seedling mortality due to fungi. Pots were fertilized with 0.15g of soluble fertilizer (20-20-20) three weeks after planting. Plants were maintained at 80° F ± 9°

---

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

with a 16 hr photoperiod of natural lighting supplemented by sodium vapor lights for the first run and 15 hr. photoperiod with natural lighting and similar temperatures for the second run.

Four weeks after planting, percent cover by species was estimated for each treatment. Also, treatments were harvested, separated by species, dried at approximately 160° F for 3 days, and weighed. Total plant weight (by species) in a mixture was divided by the total plant weight of a pure stand to obtain the relative yield of a species at a given ratio. Observed relative yields (by species) were compared with expected relative yields to determine any case of interference. Data were analyzed using analysis of variance. Runs could not be combined due to treatment by run interactions. Significant differences between the observed and expected values were determined with Fisher's Least Significant Difference (LSD) where the F-test indicated significance ($P \leq 0.05$).

RESULTS

First, this report focuses on percent ground cover as an indication of interference and then dry matter production. Observed percent cover by species compared with expected values indicated no suppression of barnyardgrass, common lambsquarters, or redroot pigweed by Mogul (Figures: 1, 2, and 3). Anytime there was a significant difference between the observed and predicted weed cover it was due to increased weed cover. Weed cover was never less than expected. Alternatively, Mogul percent cover was generally close to the predicted value.

Overall, Mogul and weed dry matter yield data supported the percent cover data, which was that Mogul did not interfere with weed growth. Barnyardgrass consistently yielded more dry matter than expected in both runs (Figure 4). In run 1 there was one case (50:50 ratio) where common lambsquarters produced significantly more dry matter than expected (Figure 5). In the remaining treatments common lambsquarters dry matter yields were within predicted values. Redroot pigweed dry matter yields were inconsistent between run 1 and run 2 (Figure 6). The first run indicated enhanced redroot pigweed growth when raised in combination with Mogul medic at 50% or 25% weeds in a pot. Conversely, the second run indicated one case (75:25 = weed:medic) where Mogul interfered with redroot pigweed. Analysis of Figure 6 leads one to question the ability of Mogul to interfere with redroot pigweed because reported suppression occurred at the low Mogul density. If interference occurred with 25% Mogul in the pot why was there no interference when medic was present in the pot at 50 or 75%?

CONCLUSIONS

There was insufficient evidence to demonstrate that Mogul medic interferes with barnyardgrass, common lambsquarters, or redroot pigweed. If anything, the data may suggest that Mogul enhanced weed growth in some cases rather than interfered with weed growth. Weeds frequently responded to the medic/weed interaction by increasing growth, whereas, Mogul generally seemed uninfluenced when grown in combination with one of the three weed species.

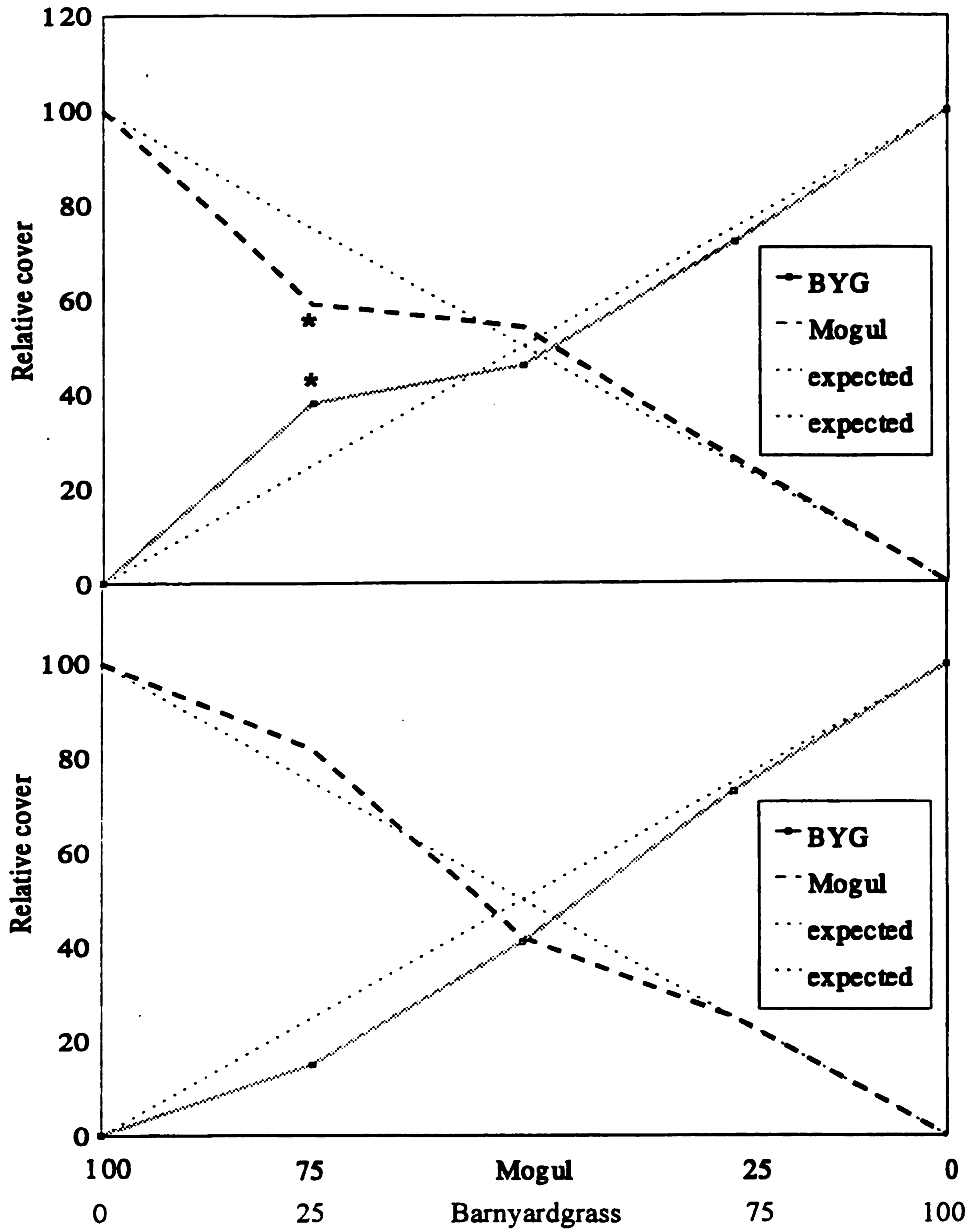

Figure A.1. Mogul/barnyardgrass relative cover from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference ($P \leq 0.05$) of the observed and expected value.

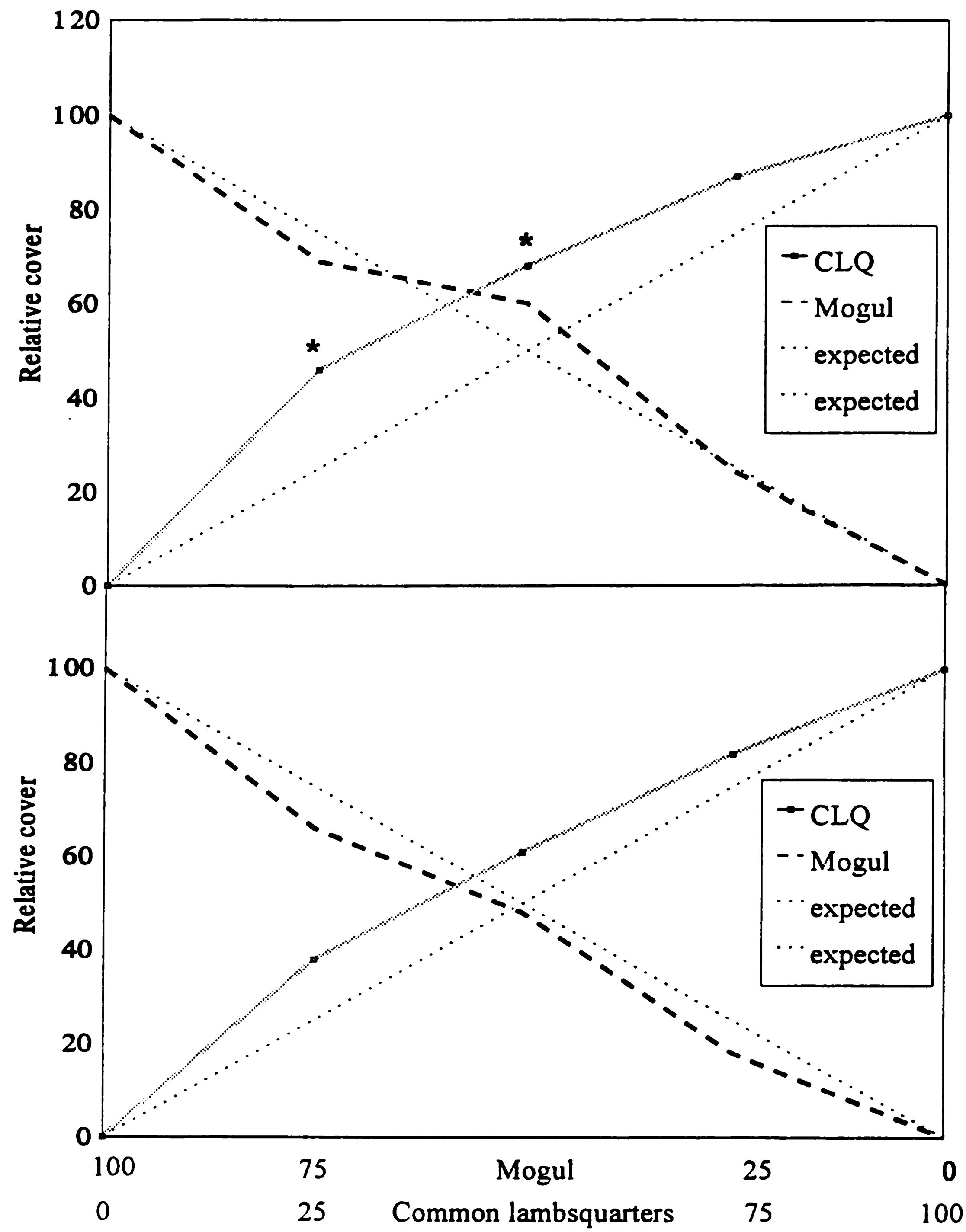

Figure A.2. Mogul/common lambsquarters relative cover from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference (P≤0.05) of the observed and expected value.

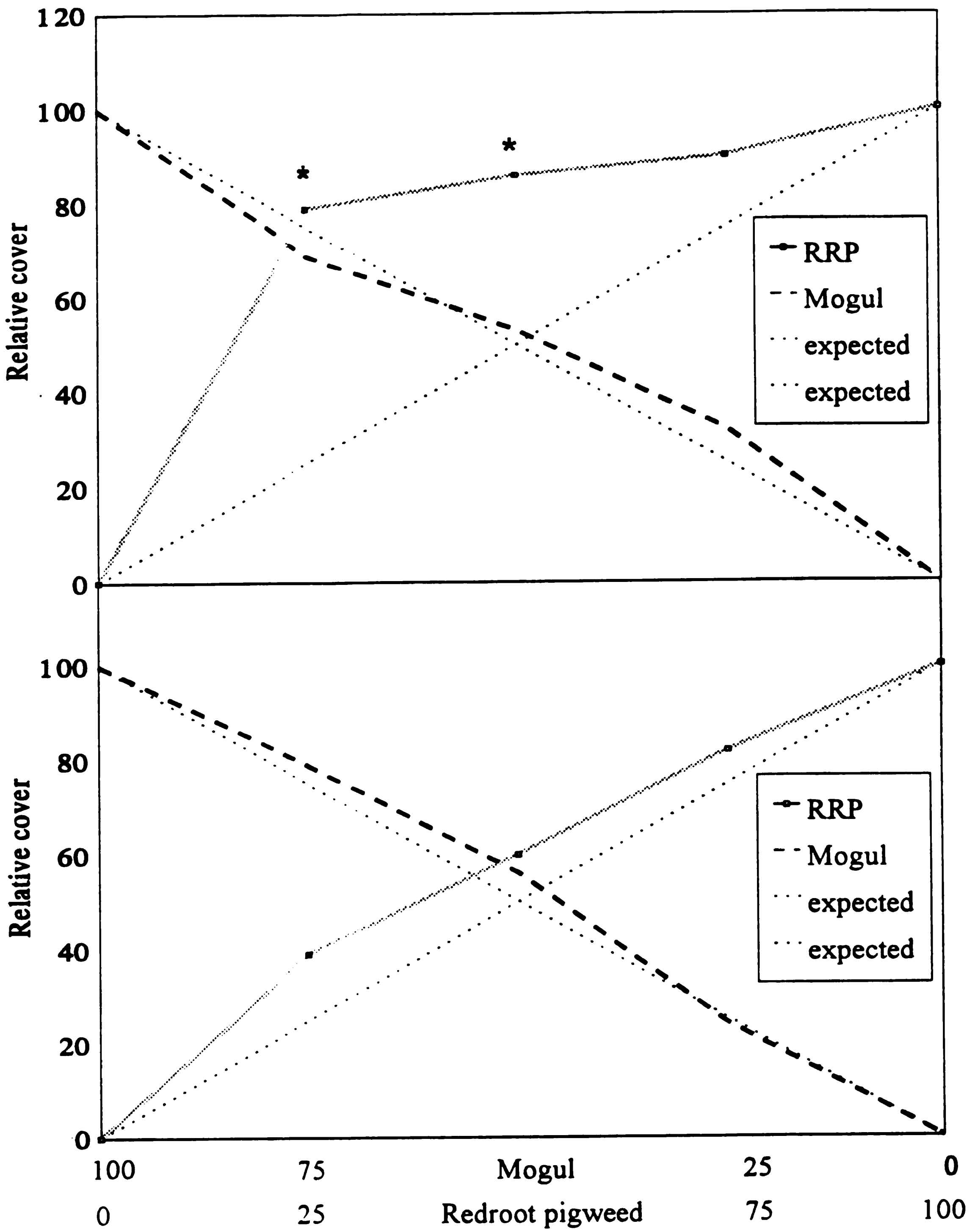

Figure A.3. Mogul/redroot pigweed relative cover from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference (P≤0.05) of the observed and expected value.

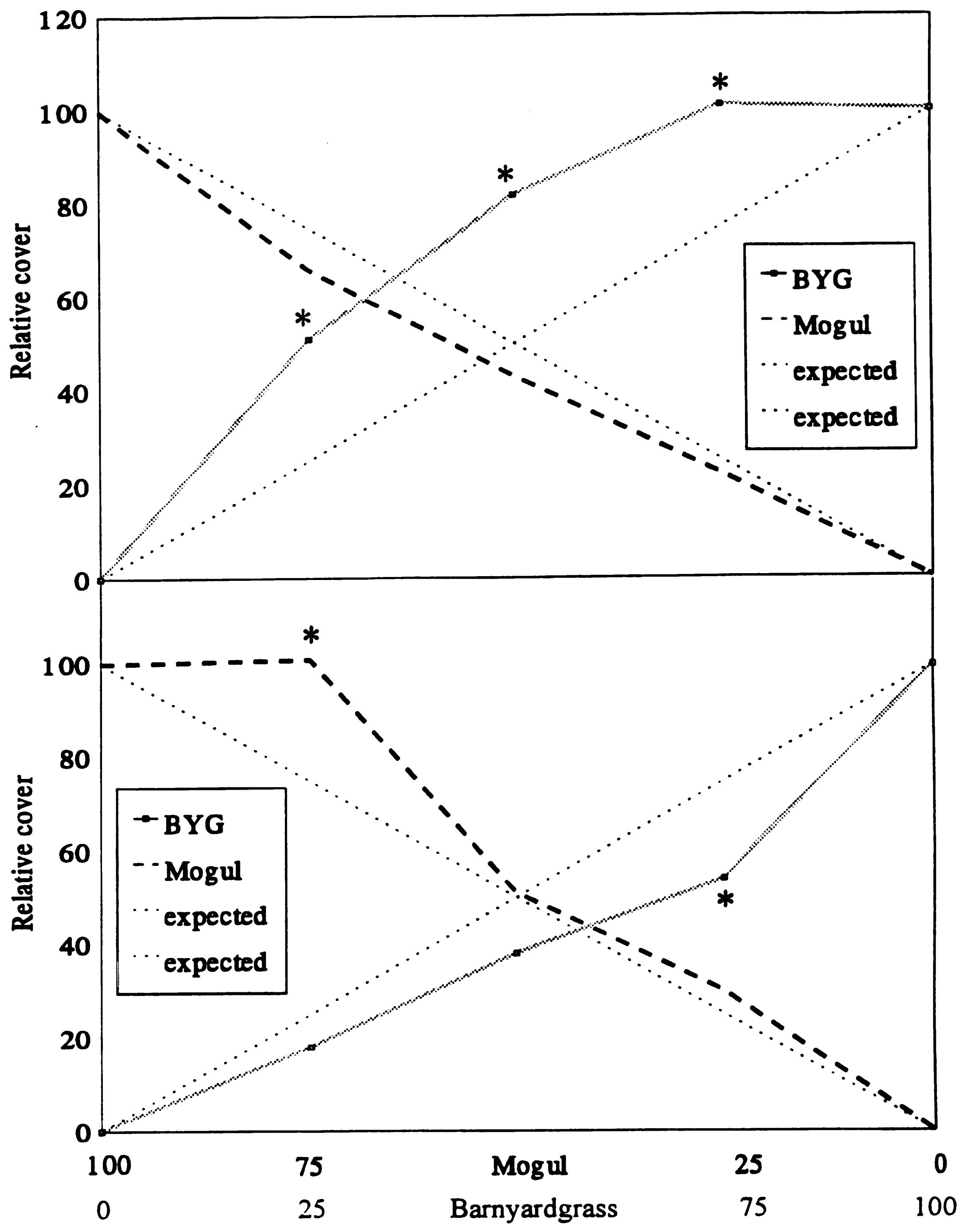

Figure A.4. Mogul/barnyardgrass relative dry matter yields from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference (P≤0.05) of the observed and expected value.

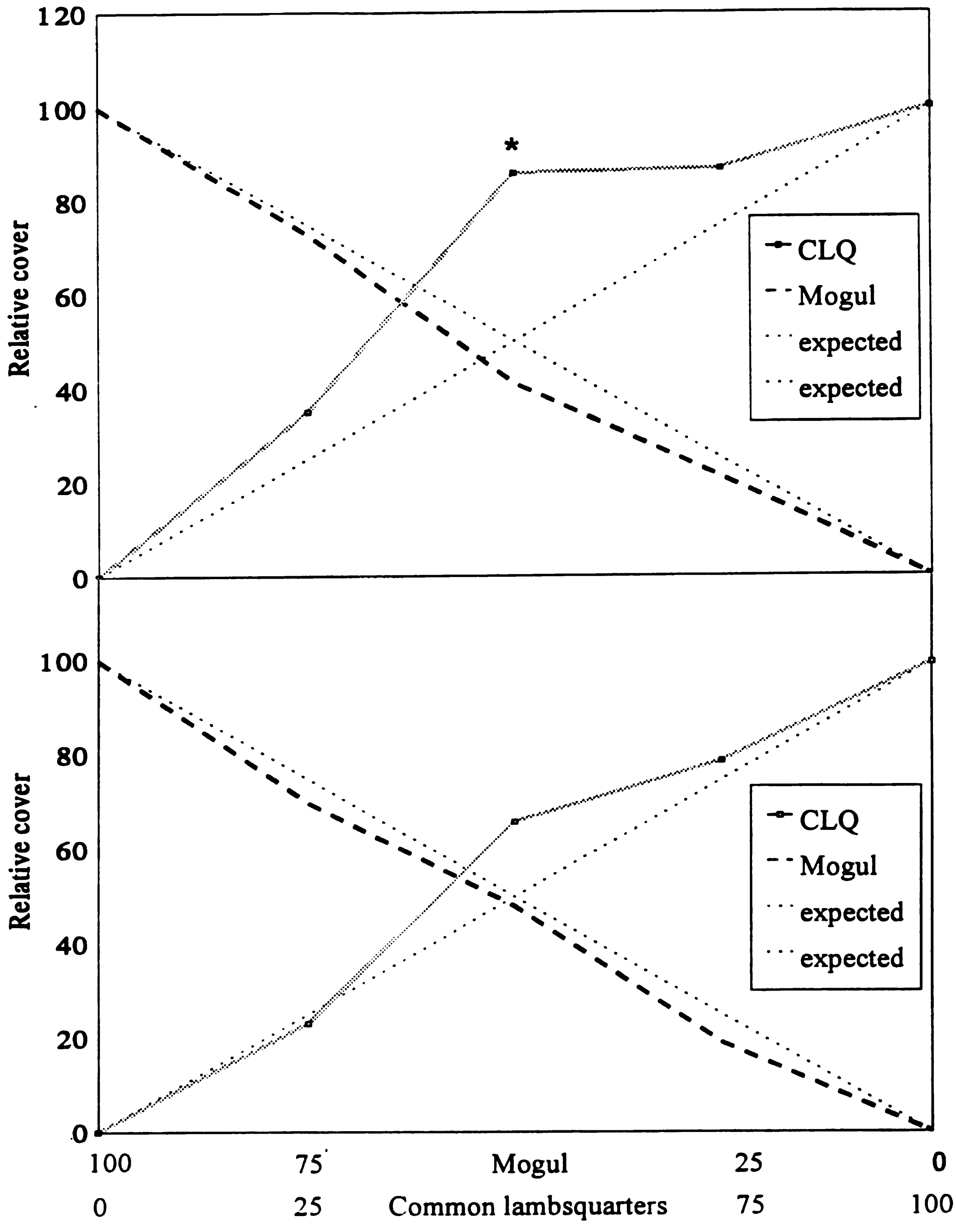

Figure A.5. Mogul/common lambsquarters relative dry matter yields from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference (P≤0.05) of the observed and expected value.

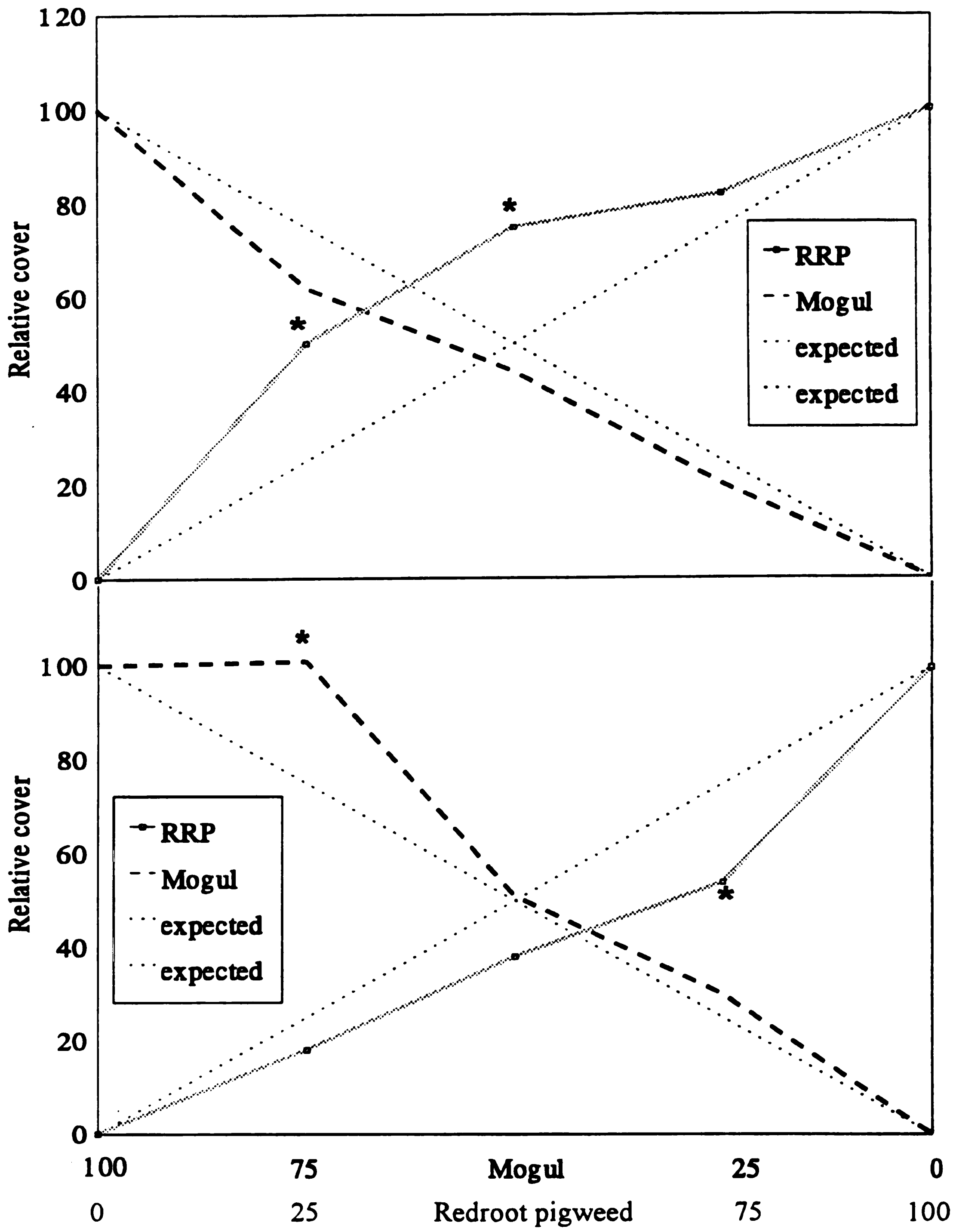

Figure A.6. Mogul/redroot pigweed relative dry matter yield from each species in a treatment. Run one is the top half of the figure and run two is the bottom half. An * represents a significant difference (P≤0.05) of the observed and expected value.

APPENDIX B

Table B.1. Plant height four weeks after herbicide application in greenhouse trials.

Herbicide/rate	Alfalfa run 1	Alfalfa run 2	Berseem run 1	Berseem run 2	Mogul run 1	Mogul run 2	Santiago run 1	Santiago run 2
	% of untreated							
EPTC 1x	70 b†	72 b	60 bc	97 a	93 ab	91 a	100 a	84 ab
EPTC 2x	53 bc	74 b	69 b	95 a	88 bc	97 a	100 a	86 ab
Metolachlor 1x	34 cd	57 bc	41 bcd	31 bc	70 cde	63 b	92 a	79 ab
Metolachlor 2x	34 cd	34 cd	43 cd	5 cd	57 de	67 b	45 b	54 b
Pendimethalin 1x	61 bc	33 cd	62 bc	38 b	73 cde	29 c	87 a	92 a
Pendimethalin 2x	64 bc	9 d	23 de	23 bc	53 e	0 c	89 a	83 ab
Cyanazine 1x	0 d	0 d	0 e	0 d	0 f	0 c	0 c	0 c
Cyanazine 2x	0 d	0 d	0 e	0 d	0 f	0 c	0 c	0 c
Control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

Table B.2. Number of plants that emerged and were alive four weeks after herbicide application in greenhouse trials.

Herbicide/rate	Alfalfa run 1	Alfalfa run 2	Berseem run 1	Berseem run 2	Mogul run 1	Mogul run 2	Santiago run 1	Santiago run 2
	% of untreated							
EPTC 1x	86 ab†	100 a	60 cd	100 a	72 bc	56 bc	89 a	88 ab
EPTC 2x	74 ab	88 ab	90 b	100 a	92 ab	100 a	85 a	90 ab
Metolachlor 1x	54 bc AB‡	64 bc	34 de B	78 b	70 abc AB	65 b	86 a A	56 bc
Metolachlor 2x	53 cd	48 cd A	25 ef	10 d B	56 bc	48 bc A	29 bc	45 cd A
Pendimethalin 1x	74 abc	63 bc AB	63 c	55 bc AB	61 bc	14 cd B	96 a	75 abc A
Pendimethalin 2x	60 bc A	21 de A	29 ef B	39 cd B	51 bc AB	0 d B	53 b AB	80 abc A
Cyanazine 1x	0 d	0 e	0 f	0 d	0 d	0 d	0 c	0 d
Cyanazine 2x	0 d	0 e	0 f	0 d	0 d	0 d	0 c	0 d
Control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

‡ Means followed by the same upper case letter within a row and run are not sigificantly different ($P \leq 0.05$) from each other. When no upper case letter follows a mean they were nonsignificant.

Table B.3. Plant dry matters collected four weeks after herbicide application in greenhouse trials.

	Alfalfa		Berseem		Mogul		Santiago	
Herbicide/rate	run 1	run 2	run 1	run 2	run 1	run 2	run 1	run 2
	% of untreated							
EPTC 1x	71 b†	76 bc	49 bc	97 ab	81 ab	65 b	53 b	64 bc
EPTC 2x	48 bcd B‡	79 b	62 b B	87 b	100 a A	100 a	44 b B	78 ab
Metolachlor 1x	35 bcd	42 de	20 d	36 c	69 bc	59 bc	28 c	32 cde
Metolachlor 2x	33 cd AB	25 def A	12 de B	2 d B	48 cde A	30 cd A	9 de B	17 de AB
Pendimethalin 1x	60 bc	41 cd AB	38 c	25 cd BC	60 bcd	6 d C	55 b	51 bcd A
Pendimethalin 2x	48 bc A	6 ef BC	7 de B	13 cd B	33 de AB	0 d C	21 cd B	44 bcd A
Cyanazine 1x	0 d	0 f	0 e	0 d	0 e	0 d	0 e	0 e
Cyanazine 2x	0 d	0 f	0 e	0 d	0 e	0 d	0 e	0 e
Control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

‡ Means followed by the same upper case letter within a row and run are not sigificantly different ($P \leq 0.05$) from each other. When no upper case letter follows a mean they were nonsignificant.

Table B.4. Legume dry matters harvested four weeks after herbicide application in greenhouse trials.

Herbicide/rate	Alfalfa run 1	Alfalfa run 2	Berseem run 1	Berseem run 2	Mogul run 1	Mogul run 2	Santiago run 1	Santiago run 2
	% of untreated							
Bentazon 1x	75 cd†	89 abc	75 bcd	75 abcdef	40 fg	73 b	51 def	73 bcd
Bentazon 2x	63 d	29 f	55 d	86 abcd	47 ef	62 bcd	47 ef	29 fg
Bromoxynil 1x	96 abc A‡	64 cdef A	10 e B	56 def A	11 gh B	6 e B	16 fg B	2 g B
Bromoxynil 2x	92 abc A	77 bcd A	7 e B	5 g B	0 h B	0 e B	0 f B	1 g B
Imazethapyr 1x	84 abcd	83 abc	84 abc	78 abcdef	81 cd	69 b	83 bc	93 ab
Imazethapyr 2x	70 cd	90 ab	72 cd	98 ab	67 cde	50 bcde	61 cde	91 abc
MCPA 1x	89 abc	74 bcd	70 cd	71 bcdef	72 cd	58 bcd	84 bc	92 abc
MCPA 2x	80 abcd	72 bcde	79 bc	75 bcdef	60 def	58 bcd	73 bcd	73 cd
2,4-DB 1x	92 abc	93 ab	92 ab	95 abc	68 cde	66 bc	84 bc	90 abc
2,4-DB 2x	95 abc	96 ab	84 bc	87 abcd	83 bc	67 bc	84 ab	84 bc
Nicosulfuron 1x	83 abcd	59 cdef	80 bcd	64 def	79 c	70 bc	82 b	74 bcd
Nicosulfuron 2x	81 bcd	56 def	82 bcd	43 fg	73 cd	55 bcd	79 bc	79 bc
Primisulfuron 1x	98 ab	47 ef	79 bc	59 cdef	78 cd	34 cde	89 ab	59 de
Primisulfuron 2x	94 abc	32 f	82 abc	49 fg	93 ab	19 de	87 ab	47 ef
Control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

‡ Means followed by the same upper case letter within a row and run are not sigificantly different ($P \leq 0.05$) from each other. When no upper case letter follows a mean they were nonsignificant.

Table B.5. Legume heights evaluated two weeks after herbicide application in greenhouse trials.

Herbicide/rate	Alfalfa		Berseem		Mogul		Santiago	
	run 1	run 2	run 1	run 2	run 1	run 2	run 1	run 2
	% of untreated							
Bentazon 1x	76 d†	95 ab	50 de	85 abc	31 de	73 bc	37 e	88 bc
Bentazon 2x	74 dc	76 cdefg	58 cd	85 ab	42 cd	73 bcd	43 e	83 c
Bromoxynil 1x	90 ab	85 abcd	14 e	66 cde	20 de	14 ef	39 e	15 e
Bromoxynil 2x	78 cd	87 abcd	10 e	9 f	0 e	0 f	0 f	0 e
Imazethapyr 1x	90 bcd	86 bcdef	93 ab	81 bcd	81 b	69 bcd	89 bcd	96 ab
Imazethapyr 2x	87 ab	88 abcd	90 ab	90 ab	72 bc	63 bcd	81 cd	92 abc
MCPA 1x	95 ab	76 cdefg	76 bc	65 cde	83 b	63 bcd	76 d	91 abc
MCPA 2x	91 ab	57 g	94 ab	72 bcde	79 b	68 bcd	85 cd	83 c
2,4-DB 1x	86 bcd	96 ab	88 ab	100 a	70 bc	81 b	93 abcd	96 ab
2,4-DB 2x	92 ab	94 abc	84 bc	63 ed	84 b	81 b	98 ab	92 abc
Nicosulfuron 1x	88 bcd	73 defg	89 abc	79 bcd	78 b	73 bcd	92 abc	83 bc
Nicosulfuron 2x	97 ab	70 fg	84 abc	60 cde	77 b	72 bcd	90 abc	96 ab
Primisulfuron 1x	89 abc	73 efg	90 ab	52 e	81 b	54 cde	92 abcd	63 d
Primisulfuron 2x	86 ab	61 g	90 ab	61 de	87 ab	46 de	86 bcd	64 d
Control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

Table B.6. Legume visual injury compared to the untreated control. Evaluated four weeks after foliar herbicide applications in field trials near East Lansing, MI.

	Berseem		Mogul	
Herbicide/rate	1995	1996	1995	1996
	% of untreated			
EPTC 1x	1 a†	0 a	0 a	3 a
EPTC 2x	1 a	0 a	3 a	0 a
Bentazon 1x	0 a	0 a	3 a	0 a
Bentazon 2x	1 a	2 ab	24 ab	8 a
Imazethapyr 1x	4 a	0 a	3 a	0 a
Imazethapyr 2x	3 a	0 a	3 a	2 a
2,4-DB 1x	23 ab	29 c	5 a	0 a
2,4-DB 2x	60 cd	45 d	31 b	3 a
MCPA 1x	25 ab	8 ab	36 b	34 b
MCPA 2x	40 bc	13 b	90 de	95 f
Metolachlor 1x	69 d	89 e	33 b	70 c
Metolachlor 2x	95 e	96 f	60 c	87 e
Pendimethalin 1x	97 ef	96 f	79 cd	78 d
Pendimethalin 2x	100 f	100 g	97 e	96 f

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.

Table B.7. Legume heights measured four weeks after foliar herbicide applications from field studies near East Lansing, MI.

	Berseem				Mogul			
Herbicide/rate	1995		1996		1995		1996	
	---------------- % of untreated ----------------							
EPTC 1x	95	ab†	95	abc	89	bcd	92	ab
EPTC 2x	92	ab	95	abc	88	bcd	97	ab
Bentazon 1x	97	ab	95	abc	90	abc	90	ab
Bentazon 2x	90	bcd	98	ab	73	cde	91	ab
Imazethapyr 1x	94	bc	88	abcd	88	bcd	99	a
Imazethapyr 2x	89	bcd	80	bcdef	81	bcde	100	a
2,4-DB 1x	84	bcde	81	cdef	92	ab	99	a
2,4-DB 2x	80	cde	73	def	82	bcde	91	ab
MCPA 1x	93	ab	90	abcd	74	de	77	bc
MCPA 2x	78	def	82	bcdef	48	g	29	e
Metolachlor 1x	67	efg	66	efg	69	ef	83	bc
Metolachlor 2x	56	fg	58	fgh	53	fg	49	de
Pendimethalin 1x	40	g	31	h	51	fg	71	cd
Pendimethalin 2x	0	h	28	gh	31	g	26	e

† Means followed by the same letter are not significantly different ($P \leq 0.05$) from each other. Appropriate comparisons can be made within a single collumn.