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MEDICS AND CLOVERS IN WHEAT-NO-TILLAGE CORN ROTATIONS
WITH INSIGHTS INTO THEIR USE BY FARMERS

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By

John Winfield Fisk

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ABSTRACT

MEDICS AND CLOVERS IN WHEAT-NO-TILLAGE CORN ROTATIONS WITH INSIGHTS INTO THEIR USE BY FARMERS

By

John Winfield Fisk

Forage legumes can be beneficial as cover crops in grain crop rotations typical of the north central USA. This research was conducted to investigate the potential of *Medicago* (annual medics) species and clovers as cover crops for no-tillage corn (*Zea mays* L.). Specific objectives were 1) determine legume biomass, tissues nitrogen (N) concentration, biomass N, and dinitrogen fixation ability when frost-seeded into winter wheat or planted after wheat harvest, 2) measure the effect of cover crops in the rotation in terms of plant available soil N, corn grain yield and biomass, fertilizer replacement value, and uptake of annual legume ^{15}N, 3) determine the effect of fall seeded legumes on weed suppression 4) investigate whether participatory approaches to the generation and dissemination of information and technologies around sustainable agriculture, specifically cover crops, may be more appropriate than conventional methods.

Annual legume cover crops established after wheat harvest demonstrated excellent potential for N_2 fixation (15.7 to 64.9 % of biomass N) and biomass N accumulation (48 to 206 kg N ha^{-1}) and were comparable to fall and frost-seeded red clover (*Trifolium pratense* L). Soil inorganic N levels were often higher following legumes than the no cover control. Fertilizer replacement values were between 24 and 112 kg N ha^{-1} for legumes, whereas, actual legume ^{15}N recovery in a following crop was between 9 and 16 % indicating rotation effects beyond N contribution.

Density and dry weight of winter annual weeds as well as dry weight of perennial weeds following, fall-planted cover crops, were almost always lower then when following the no cover crop control. The effect of cover crops on the density of summer annual and perennial weeds was not as pronounced as for spring annuals. Summer weed density and dry weight were significantly lower where cover crop residue was retained compared to when it was removed.

Evidence that participatory approaches would be effective in facilitating the generation and dissemination of sustainable agriculture technologies was found, including: a desire by farmers for more farmer-to-farmer interaction indicating an attraction to the participatory learning process, a desire by knowledge brokers for greater skills in facilitating participatory methods, and that a limited number of farmers are currently learning to integrate their farms with participatory approaches.

To my children, Tyler Fredrick and Liam Cole.

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PREFACE

Chapter 1 in this dissertation was written in the style required for publication in the *Agronomy Journal*. Significant contributions were made by Dr. Oliver Shabenburger. His contribution was in analysis of data collected by the author. More specifically: a statistical code of a higher order for the analysis of and trend description for legume biomass, tissue N, biomass N, and soil inorganic N; figures describing legume and soil N trends over time; sub-soil N analysis.

Chapter 2 in this dissertation was written in the style required for publication in the *Agronomy Journal*. Chapter 3 in this dissertation was written in the style required for publication in the *American Journal of Alternative Agriculture*.

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Chapter 1

GROWTH TRENDS OF MEDICS AND CLOVERS AND THEIR EFFECT ON YIELD AND NITROGEN UPTAKE BY NO-TILL CORN

ABSTRACT

There is need for increased cover crop options which avoid depleting available soil moisture, reduce the need for chemical control, significantly contribute N to a following crop and demonstrate positive yield effects. The goal of this research was to determine the potential of two annual medic species, Berseem clover, and red clover as fall seeded cover crops followed in rotation with no-tillage corn. Specific objectives were to i) quantify biomass, tissue N, and biomass N of the legumes over the course of growth, ii) measure legume N_2 fixing capacity, iii) measure the effect of legumes on soil inorganic N, iv) measure yield effects in terms of fertilizer replacement value (FRI), and v) measure the recovery of legume N by a following crop and in selected soil pools. The annual legume species generally reached maximum predicted biomass by mid-to late-Oct. which is equivalent to 65 to 80 days after planting. Annual legumes demonstrated excellent potential for N_2 fixation (15.7 to 64.9 % of biomass N) and biomass N accumulation (48 to 206 kg N ha^{-1}). Soil inorganic N levels were higher following all legumes in 1995 than in the no cover control, and higher following only red clover in 1996. Early season sub-soil NO_3-N following cover treatments were increased at the 30-60 cm depth in 1995, however, there were no significant differences at 60 to 90 cm depth. Fertilizer replacement values were between 24 and 112 kg N ha^{-1} for annual legumes. Legume ^{15}N recovery in a following crop was between 9 and 16 % of input with soil retention between 47 and 65 %.

INTRODUCTION

Legume cover crops used in no-till corn systems can supply biologically fixed N to a succeeding corn crop (Decker et al., 1994; Ebelhar et al., 1984; Holderbaum et al., 1990;). Cover crops may also provide positive rotation effects (Hesterman et al. 1986). Rotation effects are yield increases which are not attributable to N from the cover crop. Long-term use of cover crops has been shown to enhance soil productivity by changing physical and chemical properties (Smith et.al 1987).

Most legume cover crops which have been evaluated are considered winter annuals since they are established in the fall and survive the winter, with spring regrowth being chemically controlled prior to crop planting. Cover crops can be established by seeding after crop harvest, inter-seeding into a standing crop, or spring frost-seeding into an over-wintering crop (Hesterman, 1988, Stute et al. 1993). In northern parts of the mid-west and the eastern USA, it can be difficult to fit cover crops into established cropping systems. The length of the growing season may not allow fall planted cover crops to survive the harsh winters or protect the soil during the fall and early spring. To maximize time for growth, frost-seeding legumes and full-year rotations have traditionally been used. Frost-seeding red clover (*Trifolium pratense* L.) into winter wheat, by broadcasting seed onto the soil surface in late-winter before the soil warms, is a traditional means of establishing a red clover cover crop. A full-year rotation means that crops such as alfalfa (*Medicago sativa* L.) or red clover, once established, are allowed to occupy the field for an entire year or longer. These crops can be cut for hay or grazed and followed by a grain crop the next year to take advantage of rotation effects and N contribution. These traditional methods are reliable but have their drawbacks.

One barrier to the successful use of cover crops may be soil moisture depletion in the spring of years with low precipitation (Badaruddin and Meyer, 1989; Frye et al. 1988; Hesterman et al. 1992; Tiffin, 1994). When cover crops are fall-ploughed to remove the risk of spring moisture depletion, the soil is left uncovered and susceptible to erosion. In cropping systems where a goal is herbicide reduction, killing the cover crop may present a problem. Even the use of cultivation may not completely kill some of the more vigorous species such as red clover and hairy vetch (*Vicia villosa* Roth).

There is a need for cover crops which do not deplete available soil moisture, which minimize the use of herbicides to terminate growth, and which contribute N and demonstrate positive yield effects on a succeeding crop. True annual legume species will not over-winter in northern regions of the USA. As a result, they may be able to provide the benefits which have been demonstrated for winter annuals without either reducing available soil moisture or requiring a burndown herbicide. This research was carried out to determine the suitability of annual legume species as cover crops in a cropping system common to the northern mid-west region of the USA.

Annual species of *Medicago* (annual medics), originating in North Africa and the Middle East, are adapted to a range of environmental conditions (Ewing, 1983., Lesins and Lesins, 1979). First introduced for grazing purposes into Australia and New Zealand, they are now a common component of sheep pastures and are used in ley cropping systems rotated with cereal crops (Puckridge and French, 1983). In these systems, medics provide high quality forage, contribute nitrogen and improve physical structure of the soil (Crawford et al., 1989). Ladd et al. (1983) studied N cycling in a wheat-medic-wheat rotation in Australia. Wheat recovered between 20 and 28% of the applied residue N when medic had been placed in the soil 7 months prior to planting wheat. Estimated dinitrogen fixation by annual medic pastures in Cyprus has been as high as 122 kg N ha^{-1} (Papastylianou, 1987).

In Montana, small grain yields were doubled following medic compared to following fallow in rotation (Sims and Slinkerd, 1991). As a green manure crop before wheat in North Dakota, black, snail and barrel medics yielded 37, 85, and 79 kg N ha^{-1} (Gardener et al., 1991). Although N accumulation was lower than in hairy vetch, vetch reduced soil moisture significantly more than the medics. Annual medic biomass yields in the north-central USA planted as a forage legume or green manure have ranged between 1.2 and 6.2 Mg ha^{-1} with biomass N up to 140 kg N ha^{-1} (Moynihan et al., 1996; Shrestha, 1996; Zhu et al., 1996).

In addition to annual medic species, Berseem clover (*Trifolium alexandrinum* L.) was investigated in this study. Berseem clover is an annual legume used as a forage plant in India and in areas with Mediterranean climates. As a hay crop it has the potential to produce large amounts of biomass rapidly and can be cut several times a year. Wescott et al. (1995) reported biomass N of 125 to 200 kg N ha^{-1}.

The goal of this research was to determine the potential of two annual medic species, berseem clover, and red clover as fall seeded cover crops followed in rotation by no tillage corn. Specific objectives were to:

1) Characterize the biomass, tissue N, and biomass N of the legume cover crops over the course of growth.
2) Measure legume N_2 fixing capacity.
3) Measure the effect of legumes on soil inorganic N.
4) Determine the effect of legumes on no-till corn yield.
5) Measure the recovery of legume N by a following crop and in selected soil pools.

MATERIALS AND METHODS

Experiments were conducted in the 1994-5 and 1995-6 growing seasons at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing (EL), MI and at the Kellogg Biological Station (KBS) in Hickory Corners, MI. Separate sites were used each year at each location. Soils were a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualf) at EL and a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf) at KBS. The experiment consisted of five cover crop treatments in a randomized complete block design with 4 replications at each location.

The cropping system in this study was winter wheat (*Triticum aestivum* L.) / cover crop / no-till corn (*Zea mays* L.) rotation. The cover crops were either frost seeded into wheat or planted after wheat harvest. Annual legume species winter killed and red clover was killed with a pre-plant herbicide in the spring prior to planting no-till corn.

Cover Crop Management

Cover crop treatments included two annual medic species; Santiago burr medic (*Medicago polymorpha* L. cv. Santiago) and Mogul barrel medic (*M. truncatula* Gaertn. cv. Mogul), as well as Bigbee berseem clover (*Trifolium alexandrinum* L.), Michigan red clover , and a no-cover crop control. White winter wheat (Chelsa) was fall planted in the year preceding cover crop planting at 2.8 kg ha^{-1}. Fertilizer was applied according to soil test results. In 1993 at EL, liquid manure containing 133 kg N ha^{-1} was applied. Cover crops were no-till drilled into wheat stubble (straw removed) on 8 August and 9 August in 1994 at EL and KBS, respectively, and on 9 August and 11 August in 1995 at EL and KBS, respectively. Legume plot size at EL was 3 m by 33.4 m and at KBS was 4.5 m by 33.4 m. Planting was done with a John Deere Power-Till No-Till Drill in rows 20 cm apart to a depth of 1 to 2 cm. Annual medics were seeded at a rate of 269 live seeds m^2. This translated into seeding rates of 13.4 kg ha^{-1} for Santiago medic and 15.7 kg ha^{-1} for Mogul medic. Red and berseem clover were planted at 16.8 kg ha^{-1} which is the commonly used rate for red clover in MI. Annual medics were inoculated with a 50 - 50 mixture of *Medicago* "A" and *Medicago* "N" (Liphatech, Inc. Milwaukee, WI). Berseem clover did not establish at EL in 1995 due to a clogged planter. When Berseem was reseeded several weeks later it failed to produce consistent stands.

Prior to cover crop planting each field received a pre-plant herbicide application of glyphosate (N-(phosphonomethyl)glycine) at 1.68 kg a.i. ha^{-1} with .1% non-ionic surfactant (NIS). In addition, sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclo-hexen-1-one) was applied at .32 kg a.i. ha^{-1} with

2.31 L h^{-1} COC: at EL on 19 August 1994 to control volunteer wheat and at KBS 12 September in 1995 to control large crabgrass (*Digitaria sanguinalis* L.) and quackgrass (*Elytrigia repens* (L.) Beauv.).

Prior to corn planting in the spring of the year following cover crop planting, each field received a burndown application of glyphosate at 1.68 kg a.i. ha^{-1} with .1% non-ionic surfactant (NIS); 2,4-D ester (2,4-dichlorophenoxyacetic acid, butoxyethylester) at .532 kg a.i ha^{-1} and .5 % NIS. At both locations in 1994, red clover was not killed by the burndown herbicides. As a result, red clover plots were mowed by hand at EL, avoiding the corn seedlings, followed by an application of dicamba (3,6-dichloro-2-methoxybenzoic acid) at .56 kg a.i ha $^{-1}$ to red clover re-growth which resulted in complete kill. Also in 1994 at EL, bentazon (3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one2,2-dioxide) at .84 kg a.i. ha^{-1} with 2.31 L h^{-1} COC was spot-sprayed for nutsedge (*Cyperus esculentus* L.) control on 3 June.

Corn Management

Corn (Pioneer 3751) was planted using no-till equipment in mid-May of each year at 62,220 seeds ha^{-1} at a row spacing of 0.76m. Main plots were split into four subplots, each 6.1 and 7.6 m in length in 1995 and 1996, respectively. Subplots received either O, 67, 134 or 202 kg N ha^{-1} as side-dressed ammonium-nitrate when corn was in stage V-6. Potassium and phosphorus fertilizer for corn was surface applied prior to planting according to soil test results. Post-emergence herbicide applications were made in late-June or early-July. At EL in 1995, nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide) at 0.035 kg a.i ha^{-1}; bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at .28 kg a.i. ha^{-1}; with .25% NIS was applied. At KBS in 1995, sethoxydim at .21 kg a.i. ha^{-1} with 2.31 L h^{-1} COC was used. At EL in 1996, bromoxynil was applied at .28 kg a.i. ha^{-1} with .25%

NIS. Five cm of overhead irrigation water was applied to all plots in 1996 on 20 Jul. and 19 Jul. at EL and KBS, respectively.

Plant and Soil Sampling and Nutrient Analysis

Biomass of fall seeded legumes was repeatedly sampled by taking two randomly selected 0.25 m^{-2} quadrates on each of four sample dates beginning approximately 30 days after planting. Measurement dates varied slightly between locations. Frost-seeded red clover was sampled in early Sept., approximately 45 days after wheat harvest, and again about two weeks later, corresponding to full flowering. Spring re-growth of both red clover treatments was sampled prior to desiccation with a herbicide. Biomass was dried at °60 C to a stable weight, weighed and ground to pass though a 2mm screen. Total N content of legume tissue was determined by micro-kjeldahl digestion of 0.1 g sample in 4 ml of 12 M H_2SO_4 followed by colorimetric determination of NH_4^+ on a Lachat flow-injector analyzer using Lachat QuikChem Method no. 10-107-06-2-E.

Soil samples were taken during the spring and summer of both years following the cover treatments. Measurements were repetitive with slightly different sample dates at each location. Eight to ten soil cores, 2 cm in diameter taken to a depth of 30 cm, were pooled for each treatment plot, dried and ground and analyzed for inorganic N. Inorganic soil N (NO_3^-N + NH_4^+) was measured in filtered 1N KCL extracts colorimetrically on a Lachat flow-injector analyzer using Lachat QuikChem Method no. 12-107-04-A. Inorganic N present in the sub-soil in spring was measured on 5 May and 8 May in 1995 at EL and KBS, respectively, and 30 May and 31 May in 1996 at EL and KBS, respectively. Soil samples were taken to depth of 90 cm and split into 30 cm segments, dried, ground and analyzed for inorganic N as previously described.

Corn grain yield was measured by hand harvesting 5.3 m in 1995 and 6.1 m in 1996 of the center two rows. Grain was shelled with a mechanical sheller, weighed and sampled for dry matter and N content. Corn stover from the center two rows of each subplot was harvested with a flail-type harvester, weighed and sampled for dry matter and N content. Total N was determined as described previously for legume tissue N. Fertilizer replacement values were determined following cover crop treatments based on N fertilizer response equations of corn with no preceding cover crop.

Dinitrogen Fixation

Dinitrogen fixation of legumes was measured with the ^{15}N isotope dilution technique (McAuliffe et al., 1958) utilizing $2m^2$ un-confined micro-plots located at one end of each replication. Ammonium sulfate (10.5 atom % ^{15}N) was applied in 1994 with a watering can and in 1995 with a backpack sprayer. Shortly after legume germination 5 kg N ha^{-1} $^{15}NH_4SO_4$ diluted into 2L distilled water containing D-glucose at a C:N ratio of 20:1 was applied to the soil surface and washed in with 2 L of distilled water. Biomass in the center of the micro-plot (border of 35 cm on each side and 25 cm in between samples) was harvested at the last two cover crop biomass sampling dates. Top growth was clipped, dried, and ground to pass through a 1 mm screen to analyze for total N and ^{15}N on a Europa Scientific CN analyzer/mass spectrometer. Percent legume N derived from fixation was calculated as follows:

$$PNDFA = (1 - {}^{15}N \text{ a.e. } FC \, / \, {}^{15}N \text{ a.e. } NFC) \times 100$$

where FC = N_2 fixing crop and NFC = non-N_2-fixing crop (Rennie, 1984). In this calculation atom % ^{15}N excess for the reference crops was the mean across replications. Non-N_2-fixing reference crops used in this study were inneffective Saranac alfalfa for berseem and red clover, and *M. rugosa* cv. Paraponto, for the annual medics, which is believed to be non-nodulating unless specifically inoculated.

Tracer Experiment with ^{15}N Labeled Legume Biomass

In the fall of 1995 at EL and KBS, confined micro-plots consisting of PVC cylinders 30 cm in diameter, were pushed into the soil to a depth of 30 cm, with minimal disturbance to the soil. Two micro-plots were centrally placed within an area 3 m by 3m at EL and 4.6 m by 3 m at KBS located at one end of each Santiago medic and no-cover control plot. Medic above ground biomass was removed at the time of installation. On 1 April 1996, labeled Santiago medic biomass (6.56 atom % ^{15}N) was applied to the soil surface in each medic micro-plot, slightly moistened with distilled water and covered with a plastic netting to prevent removal of medic from the micro-plot. Micro-plots in no cover treatments were treated the same way, however with no medic residue applied.

Legume biomass was labeled with ^{15}N by applying a Hoagland fertilizer solution containing ammonium sulfate labeled at 10 atom % ^{15}N to Santiago medic growing in sand in the greenhouse. Medic biomass was harvested in a semi-mature stage by clipping at the soil surface and dried at 60 °C to a stable weight.

Sorghum sudangrass (*Sorghum bicolor* L. Moench) was planted into the micro-plots by hand on 28 May at EL and 22 May KBS. The area surrounding the micro-plots was planted with sorghum sudangrass using a no-till grain drill at 24.6 kg ha^{-1}. Plants were thinned to three per micro-plot shortly after germination. No fertilizer N was applied to sorghum sudangrass. Sorghum sudangrass in all micro-plots was harvested three times: 52, 80, and 105 days after planting (DAP) at EL, and 57, 88, and 117 DAP at KBS. Sorghum sudangrass biomass was dried and analyzed for total N and ^{15}N as previously described.

On the last harvest date surface residue was collected and dried for analysis and the micro-plots were excavated by two depths; 0-10 cm and 10-30 cm. Sorghum sudangrass roots and crowns in the top 30 cm were analyzed separately from the soil. Soils were weighed, mixed and sub-sampled and then analyzed for microbial biomass N, inorganic N and total soil N. The proportion of ^{15}N in plant, residue and soil samples

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was determined by drying and grinding samples and analyzing them on a Europa Tracermass Mass spectrometer. Soil inorganic N was determined by 1N KCl extraction with analysis done on a Lachet flow-injector analyzer. Inorganic ^{15}N in KCL extracts was released as NH_3 following reduction of NO_3-N with Devarda's alloy and addition of MgO. The released NH_3 was trapped on acidified filter disks as NH_4-N (Brooks et al. 1989). The $^{15}NH_4$-N was analyzed on the Europa Scientific Tracermass after combustion of the filter disks in the Roboprep CN analyzer. Microbial biomass N was determined using the chloroform-fumigation incubation method (Jenkinson and Powlson 1988, Paul et al. 1997). Soils were stored for 1 week prior to analysis. Soils were not reinoculated after fumigation. Biomass N was calculated as $N = N_f / Kn$ where N_f = NH_4-N released during incubation and Kn = 0.57. Extracted $^{15}N_f$ was determined by diffusion methods described above. Natural abundance levels of ^{15}N were determined from soil samples and plant materials in the no cover micro-plot. Recovery of legume ^{15}N by plants and soils was calculated using the equations found in Harris and Hesterman (1990).

Experimental design for the tracer experiment was a randomized complete block with 4 replications. In each treatment plot were two micro-plots. Data from the two micro-plots were combined for a mean value which was used in calculation of the treatment means and standard error.

Experimental Design and Analysis

The basic experimental design at each location was a randomized completed block design with 4 replications. The basic design was replicated in each year at two different locations with separate randomizations. At each location, different field sites with similar soil types were used each year, as a result location was nested within year. Legume biomass, tissue N, and biomass N and soil inorganic N data were combined over year and location. Repeated observations made at various sampling dates without

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separate randomizations constitute a repeated measures design structure. Because of differences in sampling dates across locations, date of sampling was nested within years and locations. Significant interactions were investigated with simple effects tests and by calculating the appropriate LSD. Based on the patterns of significance for main effects and interactions, as derived in ANOVA (Table 7), trends over time were modeled using the Mixed procedure in SAS (SAS Institute, Inc., 1989). These second-stage models permit fitting of smooth trends treating time since conception of study as a continuous variable.

Corn yield data were combined over years and locations prior to analysis. Analysis of variance indicated significant year by location by cover interactions. As a result, corn yield was analyzed separately by year and location as a split-plot with main plots being cover treatment and subplots being applied N level. Further analysis was conducted for years and locations separately to facilitate calculation of FRVs appropriate to site conditions. Treatment comparisons were performed using the GLM procedure and regressions using the REG procedure in SAS (SAS Institute, Inc., 1989). Differences due to cover effects were determined using Fishers protected LSD. Differences in corn yield and N uptake at O N were determined by single degree of freedom contrasts and considered significant at $P \leq 0.10$.

RESULTS AND DISCUSSION

Legume Biomass

Annual legumes accumulated greater biomass than either red clover treatment at EL in 1994 (Table 2). Mogul medic had the greatest biomass (5.3 Mg ha^{-1}) followed by Berseem clover and Santiago medic (4.1 and 3.1 Mg ha^{-1}, respectively). In 1995 at EL, biomass levels were similar among cover crop treatments. At KBS, annual medics produced greater biomass than fall seeded red clover in both years (Table 3). Biomass production was similar for Berseem clover and annual medics in 1994 but Berseem biomass was lower than medics in 1995. In 1995, frost-seeded red clover and annual medics produced similar biomass. Other researchers have reported similar annual medic biomass levels. When interseeded with barley, fall growth of annual medics reached 5.5 Mg ha^{-1} under irrigation and 2.5 Mg ha^{-1} under dryland conditions (Moynihan et al., 1996). Zhu et al. (1996) reported that medics planted in the fall for hay or forage in Minnesota produced between and 5.3 Mg ha^{-1}, depending on experimental location.

Growth trends over time of fall-planted legumes were modeled based on four sampling dates selected within the planting year in order to describe and predict biomass accumulation. Legume growth differed between years and locations for the various cover species (Table 7). For example, Santiago medic displayed a cubic growth pattern in 1994 and quadratic in 1995 (Figure 1 and Figure 2). Annual legume species generally reached maximum predicted biomass by mid to late-Oct. which is equivalent to 65 to 80 days after planting. Fall-seeded red clover, a short lived perennial, displayed a linear growth pattern in all site-years except at KBS in 1995, where growth was quadratic. Frost-seeded red clover was sampled twice in the seeding year (Figure 2). Clover was just beginning to flower at the first sample and was at full-flower at the second sample, which was expected to be the point of maximum biomass.

Most growth trends indicated a maximum biomass point, especially for the annual legumes. Annual legumes typically began to die due to frost or ceased biomass accumulation upon initiation of flowering and eventually set seed. In 1994 at EL, a warm and sufficiently wet fall growing season allowed Berseem clover to flower and Santiago medic to mature and set seed. However, no peak biomass was predicted for Mogul medic at EL under these conditions, indicating that this species was able to utilize a longer growing period. At KBS in 1994, precipitation was not as frequent and these soils are more prone to drought. Under these conditions, annual legumes reached a biomass of approximately 2 Mg ha^{-1}, although Berseem clover had no predicted maximum. This is much lower than biomass levels at EL in 1994, and are similar to level in 1995, where dry and cool conditions limited growth.

In 1995, dry conditions and an early killing frost limited legume growth. Most annual legumes reached maximum biomass around mid to late-Oct. at KBS due to cold temperatures. Santiago medic reached maximum biomass at this time in both years indicating a shorter life cycle than Berseem clover or Mogul medic. In addition to temperatures and available moisture, annual legume growth appeared to be influenced by site history. In 1994 at EL, legume biomass was between 3.1 and 5.3 Mg ha^{-1}, whereas it was consistently under 2.8 Mg ha^{-1} at other site-years. The site used for the study in 1994 at EL had been planted with alfalfa two years prior to this study and had received regular manure applications. Both factors likely increased plant available soil N and enhanced physical and chemical soil properties which influence plant growth.

Legume Tissue Nitrogen

Tissue N for the legumes at maximum biomass are shown in Tables 2 and 3. Tissue N of Santiago medic was lower than for Mogul medic, Berseem and red clover in 3 of 4 site years and ranged between 23.3 and 27.2 g N kg^{-1}. Within these same site-

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years, tissue N for Mogul, Berseem and both treatments of red clover were not significantly different, ranging between 30.0 and 39.3 g N kg^{-1}.

In 1994 and 1995 at KBS, Santiago medic showed a similar cubic pattern of tissue N concentration (Figure 4). However, at EL in 1995, Santiago tissue N concentration demonstrated a linear pattern and in the range of 30.0 to 35.0 mg N g^{-1}.

For the most part, annual legume tissue N decreased as the plant matured. This would be expected in annual legumes which complete there life cycle in a relatively short period of time. For Santiago the decline was more rapid than for other species, yet tended to increase again at the end of the growth period. It is possible that annual medics responded to cooler temperatures in Oct. by increasing N uptake or N_2 fixation resulting in higher tissue N. In 3 of 4 site-years, Mogul medic had trends similar to Santiago with equivalent or higher N levels. Fall-seeded red clover will not mature in the planting year which accounts for its slow change in tissue N. Tissue N for Berseem was similar to red clover. Berseem clover is commonly used as a multiple cut forage legume, perhaps with an ability to utilize a longer growing season.

Biomass Nitrogen Yield and Dinitrogen Fixation

Biomass N yield for annual legumes ranged between 47 and 207 kg N ha^{-1} (Tables 2 and 3). Although N yield between red clover and the annual legumes was in general not significantly different, there were several exceptions: In 1994 at EL, Mogul medic and Berseem clover had greater N yield then either red clover treatment. Santiago medic N yield was greater than fall-seeded red clover in 1995 at EL, and in 1994 at KBS, Berseem clover produced greater biomass N than fall seeded red clover. Nitrogen yield was similar between frost and fall-seeded red clover and ranged between 34 and 90 kg N ha^{-1}.

Results indicate that most of the biomass N produced by the legume cover crops in the seeding year will be accumulated in the biomass by 65 days after planting (Figures

5 and 6). If conditions permit, as they did at EL in 1994, both Berseem clover and Mogul medic have the ability to utilize a greater time period for growth and N accumulation. Legume growth curves are similar to N yield curves which indicates that biomass has a greater influence on N yield than does tissue N. However, the observed low tissue N for Santiago had a major impact on N yield.

Dinitrogen fixation by fall planted cover crops was similar across site years and cover crops, with the exception of Santiago in 1994 at EL. Between 40 and 65 % of biomass N was derived from N_2 fixation (Table 2 and Table 3). Santiago medic N_2 fixation (15.7 %) was significantly lower in 1994 at EL than the other legumes. High soil N levels may have reduced N_2 fixation by Santiago medic at this site. In general, there were no differences observed in % N fixed between the annual legumes and red clover.

Spring Regrowth of Red Clover

At EL in 1995, biomass N of fall-seeded clover was twice as great as that of frost-seeded clover (Table 4). In 1996 at KBS, biomass and biomass N were greater in fall-seeded than frost-seeded red clover. Tissue N was equivalent between the two seeding times in all site-years. In 1995 at KBS and in 1996 at EL there was no spring regrowth of frost-seeded clover.

In the north-central region of the USA, frost seeded red clover has proven a reliable and effective cover crop. However, in this study there were problems associated with establishment and spring regrowth. In 1994, very dry conditions in May killed clover seedlings at KBS while severe wheat lodging at EL reduced frost-seeded red clover stands reducing both fall biomass and spring regrowth. In 1996 at EL, spring regrowth was very sparse making a reliable biomass estimate impossible.

Soil Inorganic N Following Cover Crop Treatments

Data were combined over years and locations and subjected to a repeated measures analysis over the six sampling dates. Because there was no significant location by cover effect (Table 7), the shape of the fitted trends was not varied by location (Figure 7 and 8). In 1995, all treatments displayed a slow increase in soil N between 1 May and 20 June reaching levels of 17 to 26 mg N kg^{-1} at EL and 13 to 18 mg N kg^{-1} at KBS, with higher soil N levels following legume treatments. In 1996 soil N levels increased more rapidly between 1 May and 10 June than in 1995, reaching between 19 and 27 mg N kg^{-1}. Only in early June did soil inorganic N following red clover begin to separate in magnitude from the other treatments.

Because there was no significant date by cover by location interaction (Table 7), inorganic N is presented combined over dates and locations. In 1995, soil inorganic N following legume cover crops was greater than soil inorganic N in the no cover crop control (Table 5). Berseem clover was associated with greater inorganic soil N than was either Santiago medic or red clover. In 1996, red clover was associated with greater soil inorganic N than was the no cover crop control. Cool spring conditions in 1996 may have reduced the N mineralized from winter-killed annual legumes. Occasional warm and wet periods may have resulted in losses due to denitrification, especially at EL where a large portion of the field flooded for several days. There was less potential for this loss mechanism with red clover, which was alive during most of the spring.

Early spring soil NO_3^--N levels were measured in order to determine the potential for loss of legume N through leaching. Although these data represent only one point in time, we attempted to select a time when NO_3^--N is subject to movement in the soil. Analysis of variance indicated a year by cover by depth interaction. The effect of depth would be expected with a greater level of NO_3^--N to be observed in the top 30 cm of the profile resulting from mineralization of soil organic N (Table 6). The analysis indicated a significant year by cover interaction but not a location by cover interaction. As a result data are combined over locations. A simple effects test indicated that the cover crop treatments influenced the level of soil NO_3^-N in 1995 but not in 1996 (Table 6). In 1995, soil NO_3^-N at 0-30 cm depth was greater following all annual cover crops then in the no cover crop control. At 30-60 cm, NO_3^-N levels were again higher following the annual legumes than following either red clover or the no cover crop control. In no case did we find NO_3^-N levels above 10 mg N kg^{-1}, which is considered the level above which drinking water may be unsafe for some populations.

In both years, soil NO_3 concentration tended to decrease with sampling depth. There were significant differences among cover crop treatments in the 0-30, and 30 to 60 cm depth classes, but not in the 60 to 90 class. Legume cover crop treatments did not increase soil NO_3^-N levels at the 60-90 cm depth when sampled in spring, during a period of high rainfall and increasing temperatures, when significant rates of nitrification would be expected. Stute and Posner (1995) also found there was no increase in sub-soil NO_3^-N following red clover. Nitrogen from the winter killed annual legumes may have been mineralized during brief warm and wet periods in the early spring. As a result, some of this NO_3^-N could have been washed deeper into the soil profile.

Corn Grain and Total Biomass Yield

In two of the four site years corn grain and total biomass of no-till corn was greater following cover crop treatments than following the control.. In 1995 at EL, grain yield and total biomass were unaffected by the annual legumes, but were reduced following red clover when averaged across N levels (Tables 8 and 9). The EL site, prior to this study, had a history of manure application and had been in alfalfa. As a result, the soil may have supplied enough N to the crop to preclude any further response to either cover crop N or applied N. In 1995, red clover was incompletely killed by herbicide, especially at EL, and required a second herbicide application. The living clover may have caused interruption in corn seed placement, and reduction in germination as well as a reduction in soil moisture levels (Dabney et al. 1996). Other researches have reported a reduction in available soil moisture due to over wintering cover crops and a subsequent yield reduction. (Badaruddin and Meyer, 1989; Frye et al. 1988; Hesterman et al. 1992; Tiffin, 1994).).

Grain yield and total biomass at KBS in 1995 were greater following Mogul medic and Berseem clover when compared to the no cover control (Tables 8 and 9). In 1996 at EL, grain yield and total biomass were greater following all cover treatments verses the control. There were no significant differences in grain yield or biomass at KBS among cover crop treatments in 1996. Dry conditions coupled with a well drained soil at KBS created moisture stress in the corn and limited yield.

There was no significant response to N fertilizer by corn grain and total biomass across cover crop treatments at EL in 1995 and a quadratic response at KBS in 1996 (data not shown) with no significant cover by N interactions. A significant cover crop by N interaction for corn grain was observed at KBS in 1995. Corn grain following Berseem clover and Mogul medic did not respond to N fertilizer (Figure 9), with means of 8.21, and 8.15 Mg ha^{-1}, respectively, suggesting adequate N provided by the cover crop. Grain yield following Santiago medic and the no cover control crop displayed a linear and quadratic response, respectively. At the highest fertilizer N rate in the control treatment, a corn grain yield decrease was noted, perhaps due to the lower number of plants in this treatment compared to the field average.

At EL in 1996, there were significant cover and N effects, but no interaction was observed (Figure 10). The response of corn grain to all cover treatments followed a quadratic trend with a tendency for yield to be lower following the no cover control and greatest following red clover treatments. Response by total corn biomass to nitrogen at KBS in 1995 and EL in 1996 were similar to those described for corn grain (data not shown).

Fertilizer Replacement Values

Fertilizer replacement values (FRI) were calculated based on corn grain yield, total biomass yield, N uptake by corn grain and N uptake by total biomass where there was significantly higher yield following a legume than following the no cover crop control at O N level (Hesterman et al. 1992). A FRI based on grain yield is most common, however, others have found the use of grain N uptake a more sensitive indicator of corn response to fertilizer N (Hargrove, 1986; Hesterman et al., 1992;). For Mogul medic, FRVs were calculated in two separate years and ranged between 22 and 108 kg N h^{-1} with greater estimates based on total biomass yield (Table 11). For Berseem clover, FRVs were 86 and 112 kg N h^{-1} based on grain yield and biomass yield, respectively in 1995 at KBS. Both red clover treatments produced significant FRVs. For fall seeded red clover, the FRI ranged between 31 and 91 kg N h^{-1} in three separate site years, with greater values generally based on total biomass yield or N uptake. One of the comparisons attempted in this study was to compare the FRI of red clover seeded in the spring verses in the fall, and then followed by no-till corn. Based on these results (Table 11) no conclusions can be drawn on this point. However, FRVs for both clover treatments in this study were lower than reported by Hesterman et al. (1992) under similar conditions (113 and 121 kg N h^{-1} based on grain yield and total N uptake, respectively.).

FRVs calculated for annual legume species, were comparable to those calculated for red clover in 1995 but lower than those for red clover in 1996. These results indicate significant positive yield effects, when measured in terms of fertilizer N, by annual legume species on no-till corn. Jeranyama (1995) reported an FRI of 40 kg N h^{-1} to a corn crop following corn interseeded with annual medic, however, Squire (1997) reported an FRI under 10 kg N h^{-1} for this same interseeding system.

Recovery of Legume ^{15}N

Measuring the response of corn to legumes in terms of the FRI combines rotation effects with actual N contribution (Hesterman, 1988). The ^{15}N method is thought to be more precise in actually measuring N contribution, and is therefore generally lower than FRI values (Harris and Hesterman, 1990). Total legume N uptake by the sorghum sudangrass following Santiago medic was 8.2 kg N ha^{-1} at EL and 14.9 kg N ha^{-1} at KBS , which is equivalent to 8.4 % and 14.3 % of the legume N applied to the soil surface, respectively (Table 13). These N uptake values are significantly lower than the calculated FRI for Santiago medic. Our results agree with other research which has found FRVs to be greater than the estimated legume N uptake using ^{15}N tracer methods (Harris and Hesterman, 1990). There was no significant FRI for Santiago medic at KBS in 1996, yet we measured 13.9 kg N h^{-1} uptake. In this case, it appears that even though a small amount of legume N was taken up by the following crop, positive rotation effects were limited by dry growing conditions.

Uptake of legume ^{15}N by the crop was lower than what others have found where over wintering cover crops were used. Ladd et al. (1983) reported uptake of N from soil incorporated *M. littoralis* (var. Harbinger) by a following wheat crop to be between 11 and 28 %. Harris et al. (1994) found 14 to 16 % of legume N taken up by corn where red clover had been incorporated into the soil. The lower values observed in this study may be due in part to the localization of the legume N on the soil surface and in the upper 10 cm of soil. Others have reported lower legume ^{15}N uptake in no-till than under conventional tillage conditions (Wilson and Hargrove, 1986; Smith et al., 1987). Sorghum sudangrass may have removed much of its N from below this depth. Soils at KBS are coarser in texture and easier movement downward of N may have increased plant access to legume N and contributed to the greater uptake of applied ^{15}N. Another factor which may have contributed to lower uptake levels is the difference in application time. Annual legumes are winter killed, increasing their time of exposure to conditions which cause N loss. Both denitrification N volatilization can occur from surface residues during wet periods. Ammonia volatilization from a *Lens culinaris* Medik. green manure was reported to be 5 and 14 % of biomass N (Janzen and McGinn, 1991). There was no evidence of movement of N below 60 cm in soil depth (Table 6) and therefore no loss of N through leaching.

Legume N absorbed by sorghum sudangrass was highest during the first 8 weeks of crop growth and became progressively less over the course of the season (Figure 11). In the first cutting 4.8 % and 8.4 % of the applied legume N had been taken up by the crop at EL and KBS, respectively. Other research has shown that the majority of legume N which mineralized in the first year is released within the first six weeks after it is applied (Wilson and Hargrove, 1986; Smith et al., 1987).

Legume N in the soil after final harvest was found primarily in the top 10 cm (Table 12). Recovery of legume N in the top 10 cm of soil was 47.3 % and 65.3 % of input at EL and KBS, respectively, and about 10 % was recovered at a depth of 10-30 cm. The microbial biomass contained 10.3 % and 13.9 % of input at EL and KBS, respectively. Recovery as inorganic N was less than 2 %. Surface residue consisting of legume residue and wheat straw contained 1.7 % and 5.3 % of input at EL and KBS, respectively.

Overall recovery of legume N in the cropping system was 69.1% and 94.1 % of input at EL and KBS, respectively (Table 13). Loss from the system was calculated to be 30.9 % or 30.3 kg N h^{-1} at EL and 3.9 % or 3.8 kg N h^{-1} at KBS. Recovery of annual legume N in soil was similar to what has been reported for legumes which are killed prior to planting. Harris et el. (1994) found between 60 and 72 % the applied legume N had remained in the soil after crop harvest. Levels at EL may have been lowered by 2 flooding events, one in mid-May and one in late-June. Conditions at EL could have supported denitrification, leaching and ammonia volatilization at various times and could have been viable means of N loss from the system. Nitrate levels in the subsoil in late

May following cover crops were no higher than in the control (Table 6). High recovery at KBS reflected a relatively dry season and the well drained soil at that site.

CONCLUSIONS

This study sought to determine the potential of several legumes as cover crops when established after wheat harvest, a period in the crop rotation which would otherwise be a fallow period. The legume cover crops in this study were successfully established and accumulated biomass N ranging from 34 to 206 kg N ha^{-1}. Biomass N for annual legumes was often the same or greater then for red clover in the seeding year, however, spring regrowth by red clover accumulated between 56 and 123 kg N ha^{-1}. Annual legumes usually reached peak biomass within 65-80 days after planting, indicating sufficient time for growth.

Corn grain following the cover crops was increased over a no cover crop control in 2 of the 4 site years. Corn grain yield was greater following several annual legume species than following red clover in 1995, however less differences were seen in 1996. The effect of the cover crops on a following no-till corn crop was measured in terms of N fertilizer replacement values (FRI). Even though annual legume biomass is winter killed and remains on the soil surface, subject to conditions which promote denitrification, ammonification, and N leaching, FRVs were comparable between annual legumes and red clover and ranged from 12 to 112 kg N ha^{-1}.

Soil inorganic N In the spring and early summer was somewhat predictive of significant FRVs. In 1995, soil tests indicated legume N mineralization with inorganic N greater following all legumes compared to the no cover crop control. This was also the year with the highest FRVs, ranging from 66 to 112 kg N ha^{-1}. In 1996, the only cover crop treatment with both significantly greater soil inorganic N and subsequent FRI was red clover (Tables 5 and 11). This confirms the usefulness of the presidedress spring nitrate test following organic N sources under no-till conditions (Meisinger et al. 1992).

Crop uptake of legume N measured using ^{15}N was lower than the respective FRI value, and lower that what other researchers have reported for legume ^{15}N uptake. Uptake of legume ^{15}N was limited by dry growing conditions, especially at KBS where 96 % of the applied N was recovered and only 16 % was in the crop (Table 13). At EL, field conditions may have promoted loss of N through denitrification and ammonification since only 69 % of the applied N was recovered with 9.7 % in the crop.

Based on results of this study, annual and perennial legumes planted after wheat harvest are a viable means of increasing diversity in the crop rotation while also enhancing yield of a following crop by contributing to N needs and positive rotation effects.

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Table 1. Monthly precipitation and mean air temperature during the growing seasons of 1994-1996 at EL and KBS, MI.

Year	Month	EL		KBS	
		Precip.	Mean Temp	Precip.	Mean Temp
		mm	°C	mm	°C
1994	May	46.2	12.7	4.0	15.8
	Jun.	185.9	19.8	174.4	21.5
	Jul.	121.2	20.9	160.2	22.4
	Aug.	143.3	18.6	119.5	21.9
	Sep.	118.9	16.7	29.6	17.9
	Oct.	80.8	10.7	73.4	12.0
	Nov.	120.7	5.7	106.7	6.9
1995	Apr.	69.3	5.2	76.8	6.7
	May	63.5	12.6	72.7	14.8
	Jun.	42.2	19.8	92.2	21.6
	Jul.	100.6	21.4	82.9	24.4
	Aug.	116.1	23.2	110.4	24.8
	Sep.	32.3	14.6	48.4	16.1
	Oct.	69.1	11.2	58.9	12.0
	Nov.	78.5	-0.7	90.8	0.8
1996	Apr.	98.0	6.1	81.9	7.1
	May.	71.9	12.6	70.3	14.5
	Jun.	140.5	19.6	130.4	21.6
	Jul.	29.5	19.7	2.56	21.3

Table 2. Legume cover crop biomass, tissue N and biomass N at maximum fall biomass at EL, MI.

	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	Red Clover FS[δ]
	Mg ha^{-1}				
Biomass					
1994	3.1 c	5.3 a	1.9 d	4.1 b	1.7 d[§]
1995	2.2 a	1.8 ab	1.3 b	--	1.9 ab
	g kg^{-1}				
Tissue N					
1994	27.2 b	38.4 a	39.3 a	34.1 a	36.7 a
1995	32.0 a	24.8 b	26.8 ab	--	25.5 b
	kg ha^{-1}				
Biomass N					
1994	85.4 c	206.7 a	71.9 c	139.7 b	62.3 c
1995	67.4 a	46.6 ab	34.2 b	--	47.7 ab
	%				
N Fixed					
1994	15.7 b	58.5 a	57.9 a	64.9 a	-
1995	45.2 a	41.4 a	55.9 a	54.8 a	--

[§] Means within a row followed by the same letter are not significantly different at $P \leq 0.05$ with Fishers Protected LSD.
[δ] Frost-seeded red clover.

Table 3. Legume cover crop biomass, tissue N and biomass N at maximum fall biomass at KBS, MI.

	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	Red Clover FS[δ]
	Mg ha^{-1}				
Biomass					
1994	2.0 a	2.3 a	1.4 b	2.2 a§	--
1995	2.8 a	2.4 a	1.7 b	1.6 b	3.0 a
	g kg^{-1}				
Tissue N					
1994	23.3 b	30.0 a	33.0 a	33.9 a	--
1995	26.1 b	31.4 a	35.0 a	31.5 a	30.3 ab
	kg ha^{-1}				
Biomass N					
1994	48.1 ab	70.6 ab	44.9 b	77.2 a	--
1995	72.1 ab	73.8 ab	58.5 b	49.8 b	89.8 a
	%				
N Fixed					
1995	41.4 a	50.0 a	46.4 a	38.3 a	--

§ Means within a row followed by the same letter are not significantly different at $P \leq 0.05$ with Fishers Protected LSD.
[δ] Frost-seeded red clover.

Table 4. Biomass, tissue N and biomass N for spring regrowth of red clover prior to burndown application.

Location	Seeding Time	Biomass§	Tissue N	Biomass N
1995		Mg ha^{-1}	g kg^{-1}	kg ha^{-1}
EL	Fall	3.0 a	41.3 a	123 a
	Spring	1.5 a	39.0 a	56 b
KBS	Fall	2.2	38.9	87
	Spring	--	--	--
1996				
EL	Fall	2.2	34.1	76
	Spring	--	--	--
KBS	Fall	2.1 a	36.9 a	78 a
	Spring	1.6 b	37.0 a	58 b

§ Means in a column within each site year followed by the same letter are not significatly different at $P \leq 0.05$.

Table 5. Soil inorganic N following cover treatments combined over location and sample date in 1995 and 1996.

Cover Treatment	1995§	1996
	mg kg^{-1}	
Santiago medic	13.0 b	14.0 b
Mogul medic	14.0 ab	14.5 b
Red clover	13.4 b	15.8 a
Berseem clover	14.8 a	13.0 b
Red clover FS	--	13.3 b
No cover	10.5 c	14.0 b

§ Means in a column followed by the same letter are not significatly different at $P \leq 0.05$.

Table 6. Soil NO_3 at three depths (cm) following cover treatments averaged over two locations in MI.[δ]

Cover Treatment	1995§			1996		
	0-30	30-60	60-90	0-30	30-60	60-90
	mg kg^{-1}					
Santiago medic	5.2 b	3.8 b	3.0 a	3.8 a	2.1 a	1.4 a
Mogul medic	6.3 bc	6.4 c	3.7 a	4.0 a	2.1 a	1.3 a
Red clover	3.7 a	2.3 a	3.3 a	3.8 a	1.0 a	1.1 a
Berseem clover	7.3 c	4.7 b	2.7 a	4.2 a	1.6 a	2.4 a
No cover	3.5 a	2.5 a	2.7 a	3.0 a	1.8 a	1.4 a

§ Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

δ Sample dates in 1995 were 5 May at EL and 8 May at KBS, and in 1996 were 30 May at EL and 31 May at KBS.

Table 7. Repeated measures analysis for legume biomass, tissue N, biomass N, and soil inorganic N.

Source	df	P value			df	P value
		Biomass	Tissue N	Biomass N		Inorganic N
Year (Y)	1	0.0007	0.0001	0.0001	1	0.0003
Location (L) [Y][§]	2	0.0001	0.0001	0.0001	2	0.0001
Block (B)	3	0.7358	0.5405	0.8012	3	0.3415
B [Y x L]	9	0.4586	0.0985	0.5173	9	0.004
Cover (C)	4	0.0001	0.0001	0.0001	5	0.0001
Y x C	4	0.0016	0.0006	0.0001	4	0.0014
L x C [Y]	6	0.3180	0.2807	0.1379	8	0.2678
Date [Y x L]	12	0.0001	0.0001	0.0001	20	0.0001
Date x C [Y x L]	35	0.0001	0.0001	0.0001	75	0.0715

[§] Brackets indicate the source of variation is nested.

Table 8. Response of no-till corn grain to cover treatments averaged over applied N levels.

	1995		1996	
Cover Treatment	EL	KBS	EL	KBS
	Mg ha^{-1}			
Santiago Medic	9.06	7.76	6.55	5.51
Mogul Medic	8.92	8.15	6.67	5.79
Red Clover	8.16	7.30	7.42	5.26
Berseem Clover	9.05	8.21	--	5.29
Red Clover FS	8.19	--	7.24	4.89
No Cover	8.84	7.55	5.59	5.49
LSD (0.10)	0.48	0.50	--	ns
LSD (0.05)	0.58	0.62	0.85	ns
LSD (0.01)	ns	ns	1.19	ns

Table 9. Response of no-till corn total biomass to cover treatments averaged over applied N levels.

	1995		1996	
Cover Treatment	EL	KBS	EL	KBS
	Mg ha^{-1}			
Santiago Medic	17.95	13.65	11.53	9.59
Mogul Medic	18.27	14.31	11.76	9.98
Red Clover	15.88	13.14	13.25	9.35
Berseem Clover	18.34	14.55	--	9.44
Red Clover FS	16.20	--	13.12	9.03
No Cover	17.62	12.84	10.05	9.82
LSD (0.10)	1.50	1.08	1.40	ns
LSD (0.05)	1.83	1.33	1.71	ns
LSD (0.01)	ns	ns	2.40	ns

Table 10. Regression equations for corn grain yield (Y) as a function of applied N (x) following cover treatments.

Year and Location	Cover Treatment	Equation	R^2
1995 KBS	Santiago medic	$Y = 6.5 + 0.013x$	0.62
	Mogul medic	NS $Y = 8.2$	
	Red clover	NS $Y = 7.3$	
	Berseem clover	NS $Y = 8.2$	
	No cover	$Y = 6.0 + 0.046x - 0.00019x^2$	0.68
1996 EL	Santiago medic	$Y = 3.8 + 0.051x - 0.00015x^2$	0.79
	Mogul medic	$Y = 3.4 + 0.060x - 0.00017x^2$	0.84
	Red clover	$Y = 4.8 + 0.047x - 0.00013x^2$	0.92
	Red clover FS	$Y = 3.9 + 0.064x - 0.0002x^2$	0.94
	No cover	$Y = 2.7 + 0.049x - 0.00013x^2$	0.73

Table 11. Nitrogen fertilizer replacement values (FRV) based on corn yield and N uptake.

	Grain Yield	Total Biomass	Grain N	Total Biomass N
	kg N ha^{-1}			
1995 KBS				
Mogul medic	85	108	--	--
Red clover	66	91	74	91
Berseem clover	86	112	--	--
1996 EL				
Santiago medic	25	--	--	--
Mogul medic	22	--	12	12
Red clover	48	57	31	35
Red clover FS	28	--	--	--
1996 KBS				
Red clover	--	--	37	39
Red clover FS	--	--	38	42

Table 12. Recovery of annual legume N applied to soil surface in selected soil pools and in surface residue in 1996 at EL and KBS, MI .

	Inorganic N	Microbial N	Total Soil N
	% of Applied		
EL			
0-10 cm	0.70 (0.03)§	7.56 (0.24)	47.25 (5.56)
10-30 cm	0.29 (0.03)	2.76 (0.13)	10.41 (0.90)
KBS			
0-10 cm	0.89 (0.06)	11.25 (0.42)	65.26 (3.26)
10-30 cm	0.49 (0.10)	2.66 (0.23)	9.60 (0.84)

§ Numbers in parenthesis are standard errors values.

Table 13. Recovery and loss of annual legume N applied to soil surface in 1996 at EL and KBS, MI.

	EL		KBS	
	kg ha^{-1}	% of Applied	kg ha^{-1}	% of Applied
Applied	97.9	100.0	97.9	100.0
Crop				
Top	8.2	8.4	13.9	14.3
Root	1.2	1.3	1.7	1.7
Soil	56.5	57.7	73.3	74.9
Surface Residue	1.7	1.7	5.2	5.3
Total Recovey	69.7	69.1	94.1	96.1
Loss	30.3	30.9	3.8	3.9

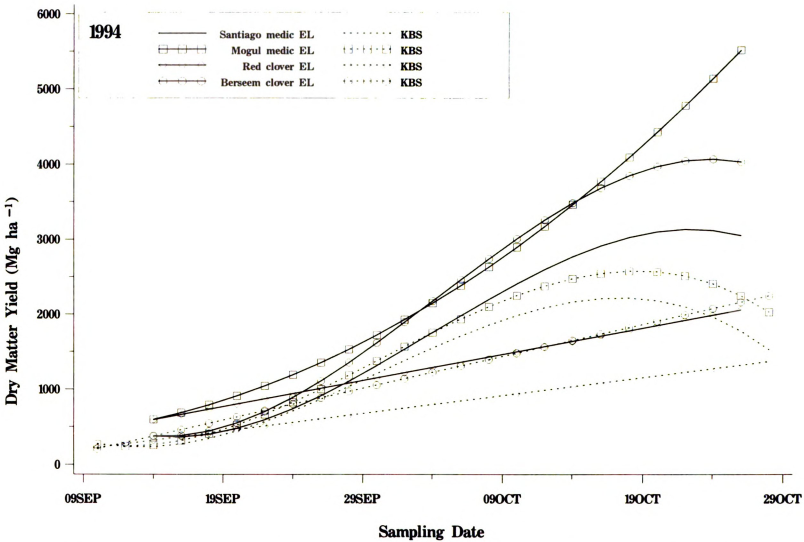

Figure 1. Fitted dry matter yield of legume cover crops in 1994 at EL and KBS.

Figure 2. Final dry matter yield of legume cover crops in 1995 at EL and KBS.

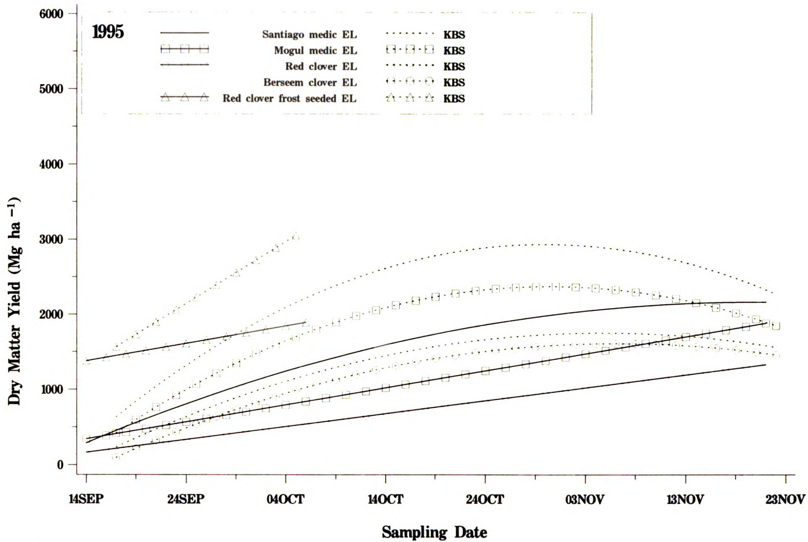

Figure 2. Fitted dry matter yield of legume cover crops in 1995 at EL and KBS.

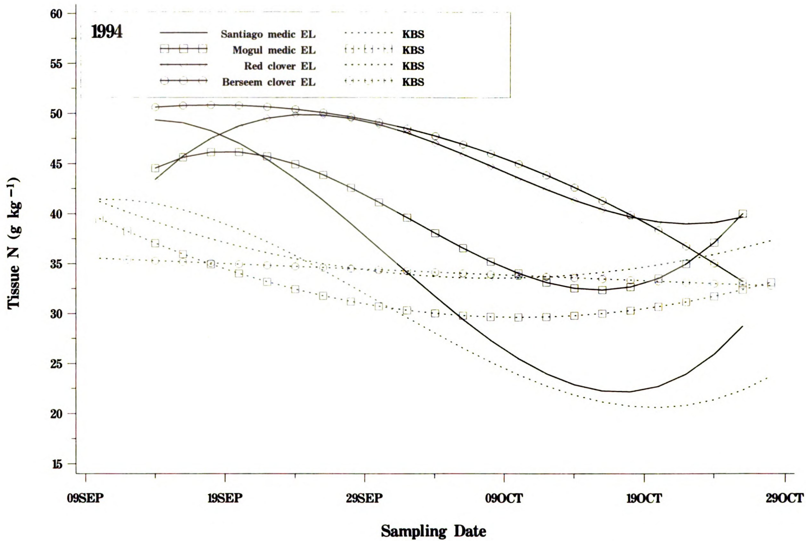

Figure 3. Fitted nitrogen concentration in legume tissue in 1994 at EL and KBS.

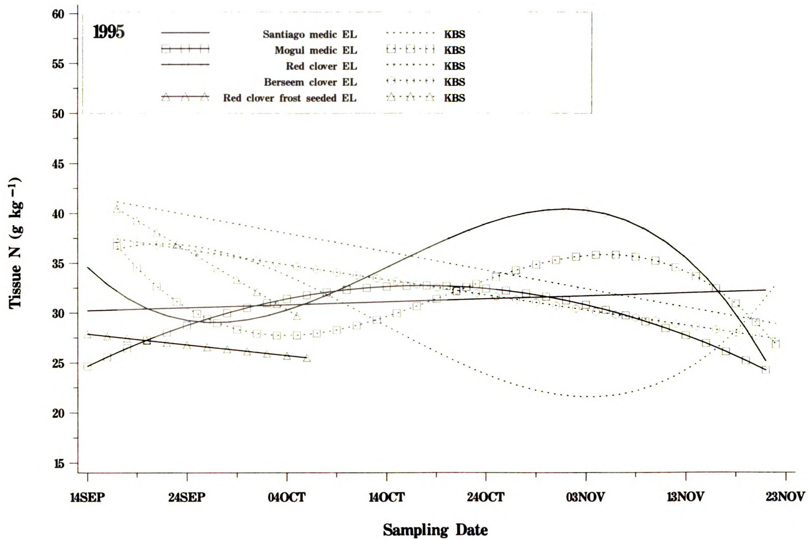

Figure 4. Fitted nitrogen concentration in legume tissue in 1995 at EL and KBS.

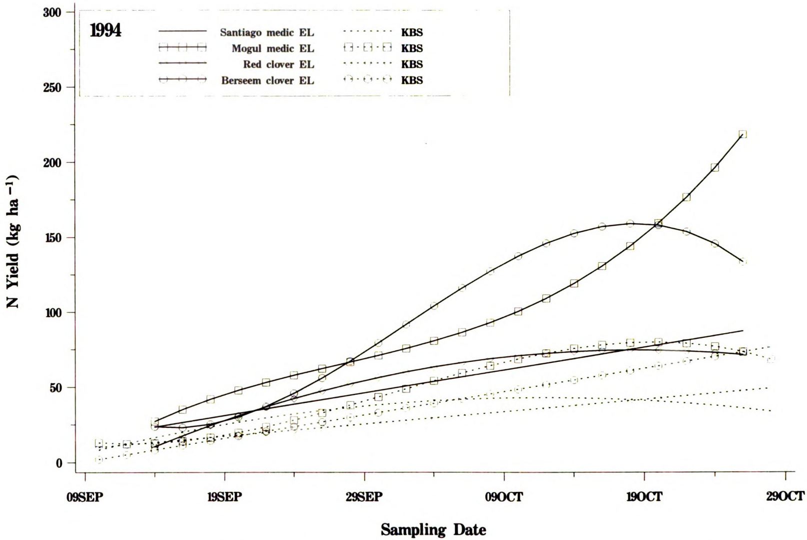

Figure 5. Fitted total N accumulated in legume cover crops in 1994 at EL and KBS.

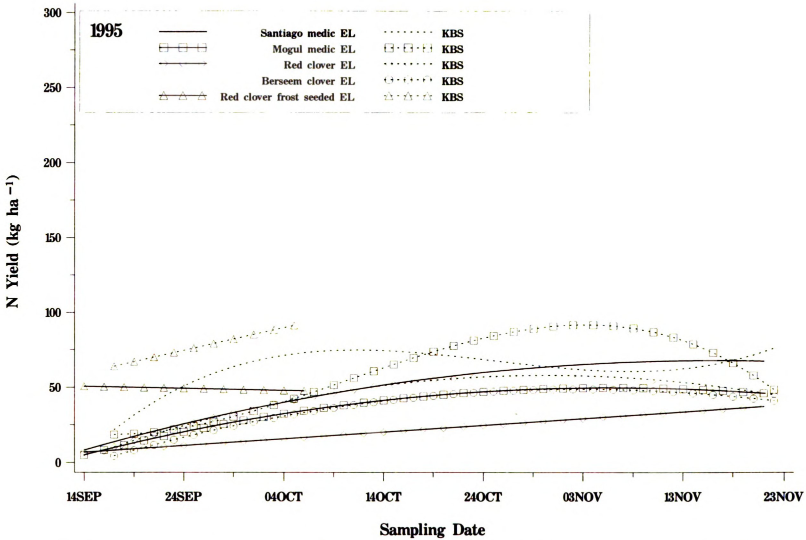

Figure 6. Fitted total N accumulated in legume cover crops in 1995 at EL and KBS.

...ablished in 1991 at EL and KBS.

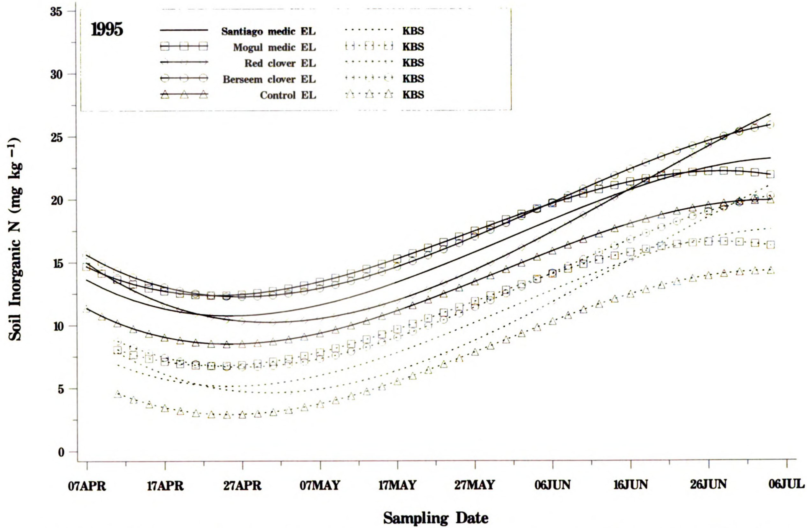

Figure 7. Fitted total soil mineral N (NH_4 + NO_3) in spring and summer following cover treatments established in 1994 at EL and KBS.

... of treatments established in 1991 at [illegible] ... spring and summer following ... [illegible] and KBS.

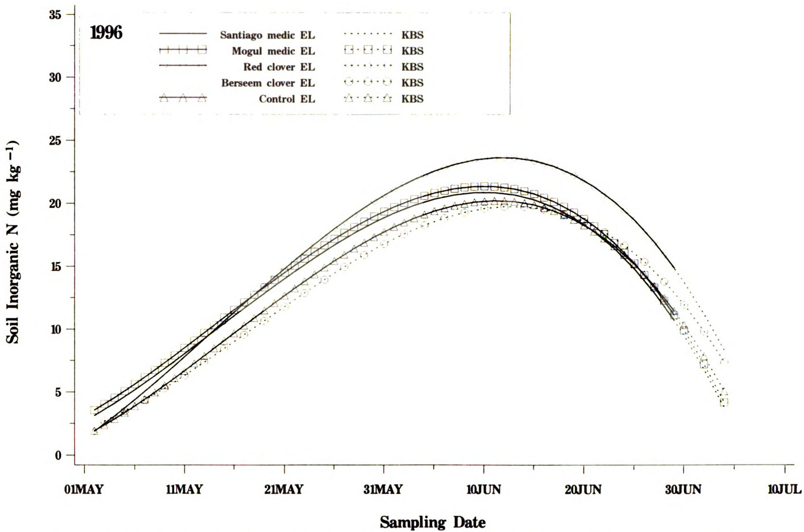

Figure 8. Fitted total soil mineral N (NH_4 + NO_3) in spring and summer following cover treatments established in 1994 at EL and KBS.

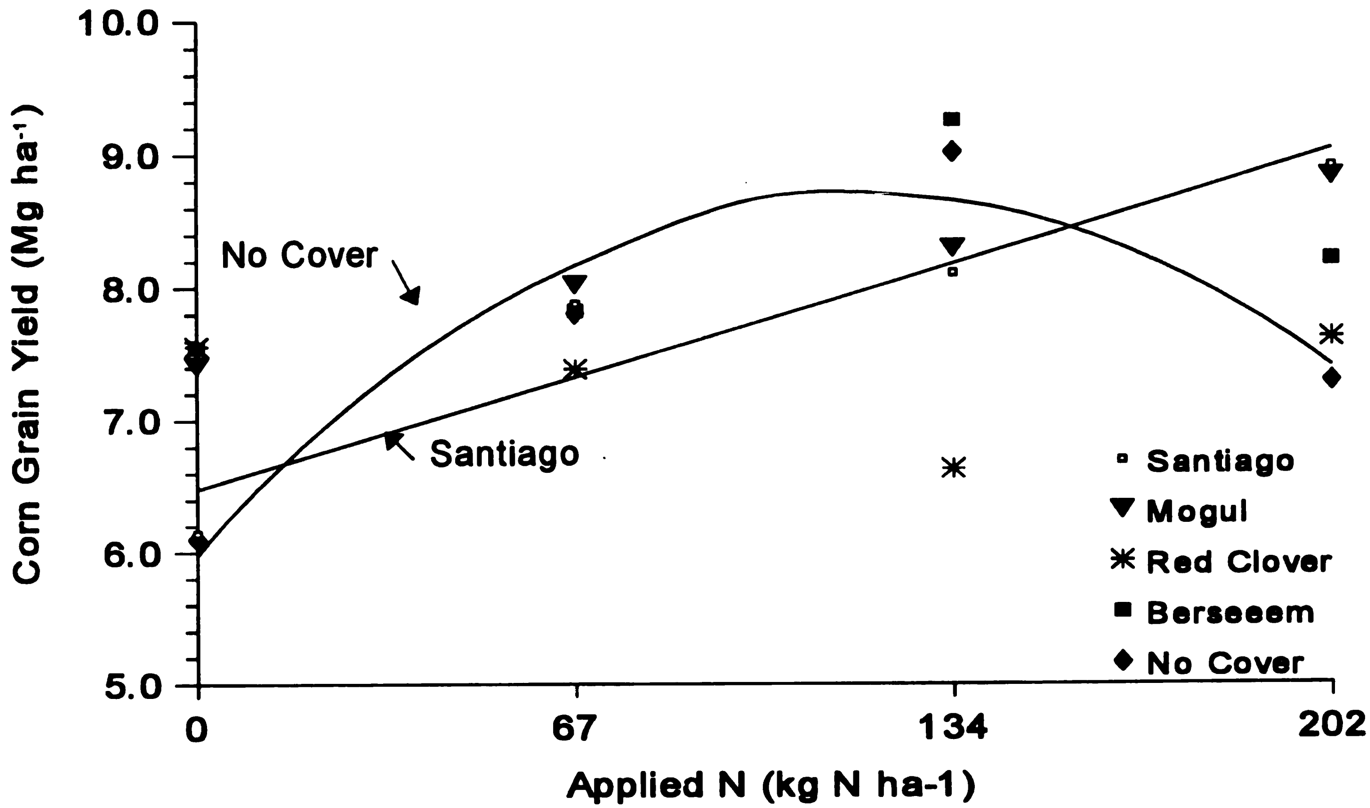

Figure 9. Corn grain yield response to applied N following cover treatments in 1995 at KBS.

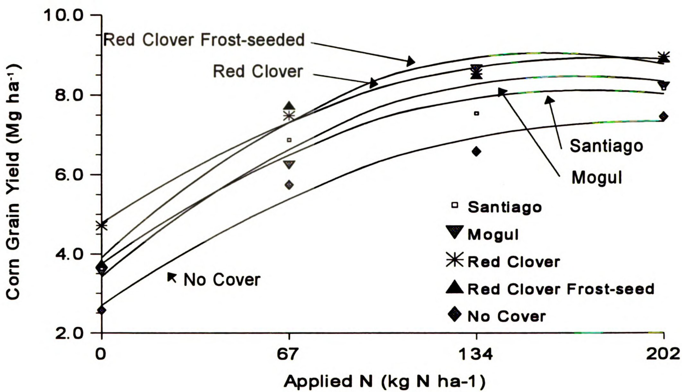

Figure 10. Corn grain yield response to applied N following cover treatments in 1996 at EL.

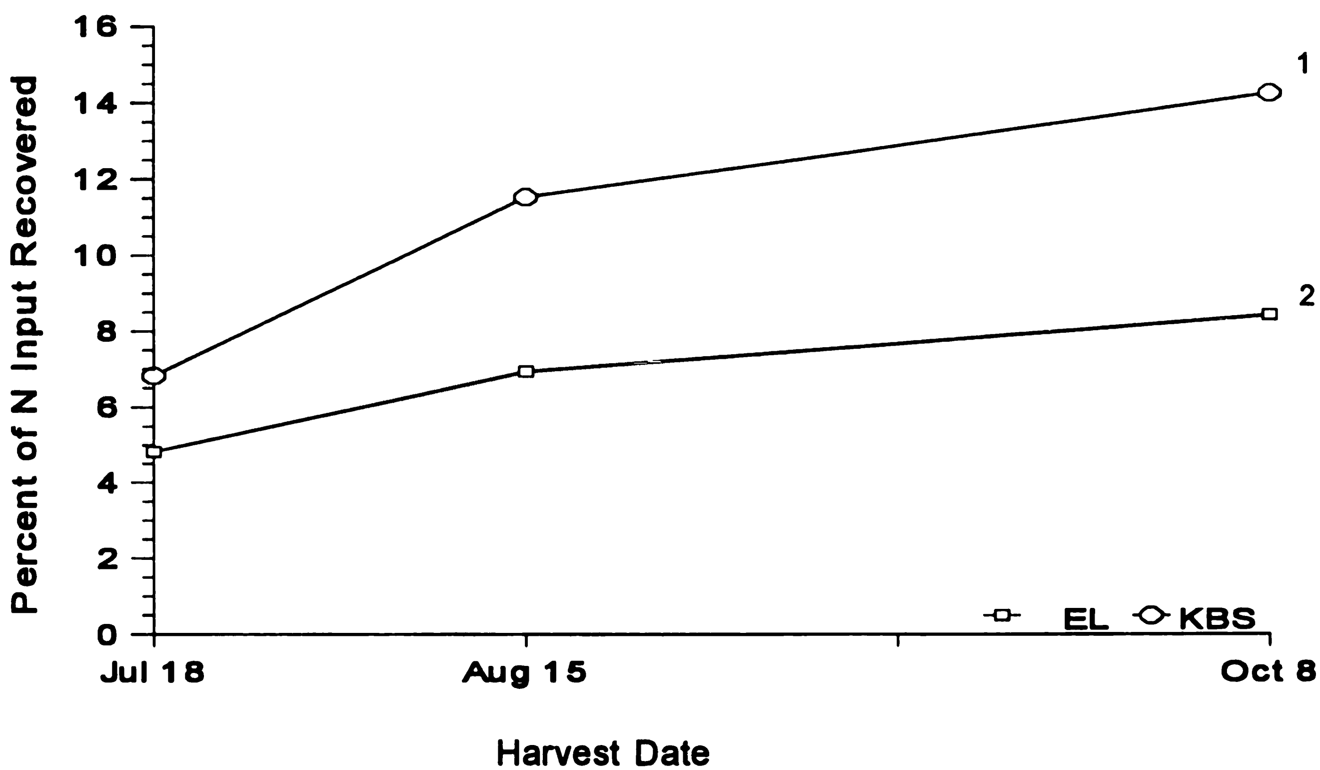

Figure 11. Uptake of 15N by sorghum sudangrass from annual medic biomass placed on the soil surface.

[1] Standard error values for harvest date one, two and three, are 0.05, 0.4, and 0.24, respectively.

[2] Standard error values for harvest date one, two and three, are 0.05, 0.09, and 0.4, respectively.

Chapter 2

WEED SUPPRESSION BY ANNUAL LEGUME COVER CROPS IN NO-TILLAGE CORN

ABSTRACT

Among the benefits provided by cover crops is the ability to reduce the density and biomass of annual weeds when used in no-till systems. Despite positive effects often produced by winter annual cover crops in corn production, there is also the potential for yield reduction due to depletion of soil moisture, N immobilization, and difficulty in cover crop management. Currently, there is interest in annual species of *Medicago* (annual medics) and other annual legumes which winter-kill for use as cover crops in mid-western grain cropping systems. This research was conducted to investigate the influence of annual legume cover crops on weed populations prior to no-till corn planting and during the early stage of corn growth. Spring annual weed density and dry weight were often reduced following annual legumes compared to no cover control. The effect on summer annual weed density was not as pronounced as for spring annuals, however, dry weights were reduced by 70 % in 1995 at both locations. Dry weight of perennial weeds sampled before corn planting were almost always lower following annual legumes compared to no cover. Perennial weed density and dry weight sampled 45 days after corn planting were reduced following annual medics in some cases. This research indicates an excellent potential for annual legumes to reduce weeds density and growth in corn grain systems.

INTRODUCTION

The use of cover crops in no-till corn production can provide a variety of benefits, both to a following corn crop and to the long-term health of the cropping system. Legume cover crops can replace fertilizer N (Fisk, 1997., Hesterman et al. 1992., Blevins et al. 1990), minimize soil erosion (Hargrove et al., 1984), maintain soil organic matter and improve soil structure (Frye et al., 1988; Smith et al., 1987), as well as reduce weed density and biomass. Hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.) and subterranean clover (*T. subterraneum* L.) have been shown to reduce weed density and dry weight of early season weeds (Yenish et al. 1996; Teasdale et al. 1991; Johnson et al. 1993).

Most legume species which are used as cover crops in no-till corn (*Zea mays* L.) production are winter annuals or short lived perennials. In northern regions of the USA, over-wintering species are normally established in the summer or fall and accumulate most of their biomass when they regrow in the spring. If allowed, they will mature and set seed in summer.

Despite the positive effects often produced by winter annual cover crops in corn production, there is also potential for corn yield reduction. Spring regrowth by legumes can lower available water in the sub-soil creating conditions of moisture stress for corn in years of low precipitation (Badaruddin and Meyer, 1989; Frye et al. 1988; Hesterman et al. 1992; Tiffin, 1994). In addition, winter annuals require some form of control, either chemical or mechanical, before or at the time of corn planting. Quick-acting herbicides are most commonly used, however, these can result in incomplete control (Yenish et al. 1996; Worsham and White, 1987). Although herbicide options for cover crop control have improved, variability of spring conditions can still lower their effectiveness. Field and weather conditions can delay application as well as reduce absorbtion of herbicides into plant tissue.

In contrast to winter annuals, true annual legume species will not over-winter in northern regions of the USA or other areas with prolonged freezing temperatures. As a result they may be able to provide the benefits of winter annuals without reducing available soil moisture and eliminate the need for control in the spring.

Currently, there is interest in annual species of *Medicago* (annual medics) and other annual legumes for use as cover crops in mid-western grain cropping systems. Originating in North Africa and the Middle East, annual medics have adapted to a range of environmental conditions (Ewing, 1983., Lesins and Lesins, 1979). Annual medics were introduced for grazing purposes into Australia and New Zealand, and are now a common component of sheep pastures. In southern Australia, annual medics are used in ley cropping systems, where they are rotated with cereal crops (Puckridge and French, 1983). In these systems, medics provide high quality forage, contribute nitrogen to the soil and non-legume pasture components and improve physical structure of the soil (Crawford et al., 1989). Berseem clover (*Trifolium alexandrinum* L.) is an annual legume used as forage plant in India and in areas with Mediterranean climates. It has the potential to produce large amounts of biomass rapidly and can be cut several times a year. (Bauchan and Sheaffer, 1994).

Recent investigations have indicated the potential for annual legumes to reduce weed populations. Sheaffer and Barnes (1994) found that weed populations were reduced where annual medics were interseeded with corn. However, in this study corn yield was also reduced, presumabley due to competition for nutrients or moisture when medic and corn were planted at the same time. Annual medics interseeded several weeks after corn planting did not affect corn yield, yet weed dry weight was not reduced either. Moynihan et al. (1996) reported a 65% reduction in fall weed biomass following a grain barley (*Hordeum vulgare* L.) and medic intercrop.

Winter wheat (*Triticum aestivum* L.) is commonly grown in rotation with corn in the midwest USA. The period between wheat harvest and corn planting is an ideal time for establishing a cover crop. Annual medics and berseem clover planted after wheat harvest have been shown to accumulate above ground biomass of between 2.1 and 5.3 Mg ha^{-1} and increase no-till corn yields (Fisk et al. 1997). This research was conducted to investigate 1) the influence of legume cover crops established after wheat harvest on winter annual and perennial weed populations prior to no-till corn planting, 2) the influence of legume cover crops on summer annual and perennial weeds, and 3) to determine the role legume residue has on summer annual and perennial weeds in this rotation system.

MATERIALS AND METHODS

Experiments were conducted in the 1994-5 and 1995-6 growing seasons at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing (EL), MI, and at the Kellogg Biological Station (KBS) in Hickory Corners, MI. Separate but nearby sites were used in each year at each location. Soils were a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualf) at EL and a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf) at KBS. The experiment consisted of five cover crop treatments in a randomized complete block design with 4 replications at each location.

The cropping system in this study was winter wheat / cover crop / no-till corn rotation. The cover crops were planted after wheat harvest and either winter-killed, if they were annual species, or were killed with a pre-plant herbicide in the spring prior to planting no-till corn.

Cover crop treatments included two annual medic species Santiago burr medic (*Medicago polymorpha* L. cv. Santiago) and Mogul barrel medic (*M. truncatula* Gaertn. cv. Mogul), Bigbee berseem clover (*Trifolium alexandrinum* L. var. Bigbee), Michigan red clover (*Trifolium pratense* L.), and a no-cover crop control. Cover crops were no-till drilled into wheat stubble (straw removed) on 8 August and 9 August in 1994 at EL and KBS, respectively, and on 9 August and 11 August in 1995 at EL and KBS, respectively.

Planting was done with a John Deere Power-Till No-Till Drill in rows 20 cm apart to a depth of 1 to 2 cm. Annual medics were seeded at a rate of 269 live seeds m^2. This translated into seeding rates of 13.4 kg ha^{-1} for Santiago medic and 15.7 kg ha^{-1} for Mogul medic. Red and berseem clover were planted at 16.8 kg ha^{-1} which is the common seeding rate for red clover in MI. Seeds were inoculated with the appropriate *Rhizobi*a spp. Berseem clover did not establish at EL in 1995 due to a clogged planter. When berseem was reseeded several weeks later, it failed to produce consistent stands.

Prior to cover crop planting, each field received a pre-plant herbicide application of glyphosate (N-(phosphonomethyl)glycine) 1.68 kg a.i. ha^{-1} with .1% non-ionic surfactant (NIS). In addition, sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclo-hexen-1-one) was applied at a rate of .32 kg a.i. ha^{-1} with 2.31 L h^{-1} COC at EL on 19 August 1994 to control volunteer wheat, large crabgrass (*Digitaria sanguinalis* L.), and quackgrass (*Elytrigia repens* (L.).

Prior to corn planting in the spring of the year following cover crop planting, each field received a burndown application of glyphosate at 1.68 kg a.i. ha^{-1} with; 2,4-D ester (2,4-dichlorophenoxyacetic acid, butoxyethylester) at .532 kg a.i ha^{-1} and .5 % non-ionic surfactant (NIS). In 1994 at both locations, red clover was not killed by the burndown herbicides. As a result, red clover plots were mowed by hand at EL, avoiding the corn seedlings, followed by an application of dicamba (3,6-dichloro-2-methoxybenzoic acid) at .56 kg a.i ha^{-1} to red clover re-growth which resulted in complete kill. Also in 1994 at EL, bentazon (3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one2,2-dioxide) at .84 kg a.i. ha^{-1} with 2.31 L h^{-1} COC was spot-sprayed for nutsedge (*Cyperus esculentus* L.) control on 3 June.

Post-emergence herbicide applications were made 45 days and 60 days after burndown in 1995 and 1996, respectively. At EL in 1995, nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide) at 0.035 kg a.i ha^{-1}; and bromoxynil (3,5-dibromo-4-

hydroxybenzonitrile) at .28 kg a.i. ha^{-1}; with .25% NIS was applied. At KBS in 1995, sethoxydim at .21 kg a.i. ha^{-1} with 2.31 L h^{-1} COC was used. At EL in 1996, bromoxynil was applied at .28 kg a.i. ha^{-1} with .25% NIS.

Corn was planted using no-till equipment in mid-May of each year at 62,220 seeds ha^{-1}. Phosporus and potassium was surface applied prior to corn planting according to soil test results, and nitrogen was side-dressed at four pre-determined rates when corn was in stage V-6. Complete details on fertilizer application and corn planting can be found in Fisk et al. (1997).

Sampling for weed density and dry weight was carried out on two separate occasions. In the first sampling, the effect of legume cover crops on spring annual and existing perennial weed populations and growth was determined. In early May, just prior to spring burndown herbicide application, the area within four randomly placed .25 m^2 quadrates was sampled for the number of weeds by species. These samples were removed and dried at °60 C for 72 hours and weighed by species. All samples were further grouped by annual and perennial species and are reported as the total of four .25 m^2 quadrates, or 1 m^2. Chickweed (*Stelleria media* L.) was sampled only for dry weight since determining the actual plant density of this species was not possible.

In the second sampling, the effect of cover crops on summer annual and perennial weed populations and growth (weeds which germinated or otherwise initiated growth after application of the burndown herbicide) was measured. This sampling was done as described above, on spots adjacent to the initial sampling within the treatment plots, approximately 45 days after burndown in 1995. In 1996, weed populations were slow to initiate growth due to dry soil surface conditions. As a result, sampling was delayed until 60 days after burndown.

Also at this time the effect of the cover crop residue on weed populations and growth was measured by comparing data from plots in which residue had been removed to data from plots in which residue had not been removed. After the pre-burndown sample was taken in early May, the legume residue was removed from the soil surface in those .25 m^2 quadrates and the spots were marked. Approximately forty-five days later, weeds were sampled in these areas for density and dry weight by species and further grouped into annuals and perennials. These results were compared to weed samples taken at the same time in adjacent, but previously unsampled, quadrates in the same cover treatment.

Soil temperatures were measured on selected dates in 1995 and 1996 to a 5 cm depth using a soil thermometer. The thermometer was inserted into 5 randomly chosen soil locations in each treatment and these values were averaged.

Data were combined over years and locations and subject to analysis of variance using a randomized complete block model with treatments arranged as split-split-plot. The main plot was the random effect of years, the sub-plot was location (changing each year), and the sub-sub-plots were the five cover crop treatments. Where interactions with year and location were significant, data were separated accordingly and re-analyzed. There were four blocks at each location.

Weed density and dry weight data taken after burndown application were transformed by taking the square root and log, respectively, prior to analysis of variance to correct for heterogeneity of variance. Non-transformed data are presented with statistical interpretation based upon transformed data. Means of each legume cover treatment were compared to the no-cover control with a single degree of freedom F-test. Data describing the residue effect were analyzed within cover treatment with means compared using a T-test.

RESULTS AND DISCUSSION

Spring annual weed density and dry weight

There was a significant year by location by cover interaction for weed density and dry weight. Therefore these data are presented by site-year. Spring annual weed density was reduced following cover crop treatments in two out of four-site years (Table 1). The greatest impact was observed at East Lansing in 1995, where weed density was reduced following all cover crops compared to the no cover control. The dominant weeds in this site-year included shepherdspurse, chickweed, penny cress and volunteer wheat (Table 7.). In 1996 at KBS, weed density was reduced following Santiago medic and Red clover. In contrast, there were no observed effects of the cover treatments on weed density at KBS in 1995 or at EL in 1996. Weed density was relatively low at these site-years compared to those where cover crops had significantly reduced weed density.

Dry weights of winter annual weeds were lower following most cover crop treatments in all site years (Table 1.). The greater observed impact on dry weight than on weed density was in part due the inclusion of common chickweed (*Stellaria media* L.) in dry weight analysis, but not in weed density. Chickweed accounted for 30 to 63% of dry weights in the no cover treatments (Table 7).

Winter annual weeds germinate in the fall and reinitiate growth in the spring, completing their life cycle by mid-summer (Stubbendieck et al. 1994) Some winter annual species may also germinate in the spring. The reduction in weed density could result from a negative interaction of the cover crop with weed seedlings in the fall. Weeds would be in competition for resources and, as a result, would not develop enough to survive the winter. In addition, weed seed germination in the fall may have been reduced by the living cover crop as a result of reduced light (Teasdale and Mohler, 1993) and moisture. Cover crop residue can modify the conditions under which weeds germinate or regrow in the spring. Surface residue can reduce light interception, soil temperature, increase soil moisture, release allelopathic chemicals, and present a physical impediment to weed seedlings (Facelli et al. 1991; Teasdale, 1996; Teasdale and Mohler, 1993). In this study, soil temperature was reduced by red clover in mid-April at KBS in 1995. No other legume reduced soil temperature before corn planting (Table 9.) Weed density and dry weight reduction resulted from factors other than soil temperature.

The growth habit of red clover differs from the other cover crops in this study in that it reinitiates growth in the spring from crowns established the previous year. At the time of sampling for winter annual weeds, red clover had grown to between 16 and 24 cm in height while the annual legumes had left a desiccated residue on the soil surface. As a result, red clover may have influenced weed density and growth through competition for light and nutrients.

Little data exist on the effect of legume cover crops on weed populations which are present prior to crop planting. Most cover crops are still alive at this time requiring either cultivation or chemical control, making the issue of weed presence unimportant. However, annual legume cover crops may permit the reduction of burndown herbicide inputs and enable a shift towards postemergence herbicide options (Teasdale, 1996). In this case, the effect of covers on winter annual and early spring weeds is of significant concern.

Summer annual weed density and dry weight

There was a significant year by location by cover interaction for summer annual weed density and a year by cover interaction for weed dry weight. Summer annual weeds germinate in the summer and complete their life cycle by fall. These weeds can reduce crop yield as a result of competition for moisture, light, and nutrients if present at significant levels.

In this study, cover crops had significant but inconsistent effects on summer annual weeds. Weed density was reduced following Santiago medic compared to the no-cover treatment in 1995 at EL, but showed no effect in other site-years (Table 2). Weed density was reduced following red clover only in 1996 at EL.

Soil temperatures taken just before or after corn planting indicate that red clover reduced temperatures during the time of summer weed germination (Table 9). The recently killed surface residue was more effective at keeping the surface soil cool than the annual legume residue which was winter killed. Only in one site year did red clover have a greater effect on weeds than did annual legumes suggesting that soil temperatures may have played a limited role in weed suppression in this study.

Similar to the effect covers had on winter annuals, the effect on summer annuals was more pronounced for weed dry weight than density. Dry weight of summer annual weeds was reduced following annual medics in 1995 compared to the no cover control but was unaffected in 1996 (Table 2). Medic biomass was generally greater in 1995 than in 1996 and may account for the differences between years (Fisk, 1997). Dominant weeds in 1995 included lambsquarters, redroot pigweed, giant foxtail, large crabgrass, and smooth crabgrass (Table 7). Our results for annual legumes match those of Yenish et al. (1996) who found biomass of weeds sampled 45 days after corn planting reduced by winter annual legume cover crops.

It has been suggested that weed biomass may be influenced less than weed density by residue from winter annual cover crops (Teasdale 1996) because weeds will compensate for lower density by increasing in biomass. This is not the case in this study and may be a function of the mechanisms used by annual legumes to limit weed growth, which at this point are unknown. However, reduced growth may have resulted from allelopathic chemicals released by the legumes or resulting from microbial metabolic activity on the residue (Worsham, 1991).

Residue effect on summer annual weeds

The effect of cover crop residue on summer weeds was tested by removing the surface residue after the first sampling (just prior to corn planting) and re-sampling in the same spot approximately 45 days later. These weed density and dry weights were compared to data from adjacent sample squares where legume residue had been undisturbed. Most weeds present would have emerged during this period since the field had recieved a burndown herbicide just after the first sampling.

Summer annual weed density and dry weight were reduced from 27 to 60 percent following annual medics (Table 3). The effect of red clover was not as consistent as for the annual medics. Weed density was reduced in 1996 but not in 1995, while dry weight was reduced in only one out of 4 site-years.

The effect of annual legumes on weed populations was greater when tested within a cover treatment plot (residue removed or not) verses when cover treatments were compared to the no cover control. Naturally occurring weed populations as used in this study have high spatial heterogeneity (Cardina et al. 1997, Forcella et al. 1992) making it more difficult to see treatment effects between cover and no-cover plots. This would have been exacerbated by the size of the treatment plots (3m or 4.6m X 30m). Samples with and without residue which were compared were done so within treatments, and so would have had more similar conditions which may provide for a better comparison of treatment effects.

Perennial weed density and dry weight

In this cropping system perennial weeds become established both in the fall following wheat harvest, in the spring as the soil warms, and during the summer months. Dominant perennial weeds in this study are shown in Tables 6 and 7. Samples were taken at two different times during the course of the season. The first was in early May, just prior to planting no-till corn corresponding to the time of a burn-down herbicide application. The second was approximately 45 days after burn-down and corresponding to the timing of a post-emergance herbicide application.

For the first sampling date, data for weed density were combined across all site-years since no significant cover interaction was found. Perennial weed density was not effected by the cover treatments prior to corn planting (Table 4). This would be expected since the most of the weeds present at this time probably established in the fall as the cover treatments were just beginning growth. However, perennial weed dry weight was reduced following most of the cover treatments by approximately 30 to 75 percent when compared to the no-cover control (Table 4). Reduced growth of perennial weeds may be a result of competition for resources in the fall and shading and reduced soil temperatures in the spring.

The effect of legume cover crops on perennial weeds which emerge at the time of or after corn planting was measured approximately 45 days after existing weeds were killed with a burndown herbicide. Since a significant year by location by cover interaction was found results are presented by site-year (Table 5). Santiago medic reduced perennial weed density at EL both years and weed dry weight at EL in 1996. Weed density was reduced following Mogul medic at EL in 1995 only. Previous research has found little effect by hairy vetch residue, at naturally occurring levels, on the density of perennial weeds such as dandelion, curly dock, and quackgrass (Mohler and Teasdale, 1993; Curran et al., 1994). Our results indicate a good potential by annual medics to reduce perennial weeds density during corn growth and weed dry weight prior to corn planting.

In 1996 at KBS, perennial weed density and dry weight were greater following red clover and than following the no-cover control. Dry soil conditions in this year may have been ameliorated by red clover residue which can conserve surface soil moisture and thereby enhance weed germination and growth.

Residue effect on perennial weeds

In all cases it was possible to combine data over site-years for both weed density and dry weight (Table 6). Perennial weed density and dry weight were significantly lower where residue was left on the soil surface for all legumes. As was observed for summer annuals, the residue effect of the cover treatments was greater when measured by removing residue within a treatment than by comparing treatments.

CONCLUSIONS

Several investigators have established that winter annual legume cover crops can reduce weed density and biomass of summer annual weeds in corn cropping systems (Yenish et al. 1996; Teasdale et al. 1991; Johnson et al. 1993). The effect of true annual legume cover crops on weed density and biomass appears to be dependent on the cropping system in which they are used. Squire (1997) found no suppression of weeds by annual medics or berseem clover interseeded into corn. Tharp (1997) reported a reduction of annual grass weeds when annual rye (*Lolium multiflorum* L.) or an annual rye/crimson clover (*Trifolium incarnatum* L.) mixture was interseeded into sweet corn, however, crimson clover alone did not reduce grass weed densities. Moynihan et al. (1996) reported lower fall weed biomass where annual medics were interseeded with barley.

Our results indicate that annual legumes planted after wheat harvest can reduce both density and dry weight of winter annual weeds prior to planting no-till corn. The effect of the annual legumes was similar to red clover, a short lived perennial species which over-winters in this region. Summer annual weed dry weight was reduced by annual legumes and red clover, however, weed density was only occasionally reduced by the legumes in this study. The suppressive effect of annual medics residue on summer annual weed density and dry weight was consistent across all site years. Berseem clover had no significant effect and that of red clover was mixed.

Perennial weed dry weight sampled in the spring prior to corn planting was consistently reduced by both annual legumes and red clover in this study, however density was unaffected. The annual medic varieties studied had a suppressive effect on perennial weeds 45 to 60 days after burndown, yet this effect was not as strong as the effect observed prior to corn planting. Residue of all legumes reduced both density and dry weight of perennial weeds.

Although annual legumes reduced weed density and dry weight in this study, any effect this may have had on corn grain yield was removed by the application of a post-emergence herbicide after the final sampling. One question which remains is: Were weed densities and dry weight reduced to the point that they would not decrease grain yield if no further control was applied? Studies of weed-crop competition have demonstrated that the relative time of weed emergence with respect to the crop is as or more important than weed density in predicting the impact on corn yield (Knezevic et al. 1994, Bosnic and Swanton, 1997). When weed seeds germinate shortly after crop emergence, there is greater impact on corn yield. The hyperbolic crop yield model developed by Cousens (1985) incorporates both density and relative time of emergence to predict the effect of weeds on crop yield. Bosnic and Swanton (1997) reported that barnyardgrass at 39 m^{-2} reduced corn yield by 14% when emerging at the 3-leaf corn stage compared to 4% at the 7 leaf stage. Based on the hyperbolic model, 1.3 m^{-2} barnyardgrass emerging with the corn was predicted to reduce corn yield by 0.3%, up to a maximum of 35% yield loss. In Michigan, Fausey et al. (1997) reported that corn grain yields were reduced up to 14% by 13 m^{-2} giant foxtail germinating 2 days after corn emergence. They concluded that the hyperbolic model accurately predicted yield loss at low foxtail densities but that seasonal environmental variation affected maximum percent crop yield loss from foxtail interference.

We cannot directly use this model to predict the effect of weeds in this study since we do not have data on time of emergence. However, weed density in this study were in the same range as those in the cited studies where yields were reduced when germination was close to corn emergence. Other researchers have found cover crops reduced weeds, but not enough to eliminate the need for chemical control (Yenish et al. 1996; Teasdale 1996; Curran et al., 1994; Johnson et al. 1993). Annual legumes can reduce early season weed density and dry weight as or more effectively than red clover. Further research is needed to determine if chemical control could be reduced or eliminated when coupled with annual legumes. This should include effects of weed levels following legumes on the yield of the corn crop. In addition, long term studies using legume cover crops, including annual legumes, in no-till systems are needed to assess the role they can play in weed suppression during the initial transition period and as weed populations shift over time.

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Table 1. Density and dry weight of winter annual weeds following legume cover crops and a no cover control prior to corn planting.

	Weed Density				Weed Dry Weight			
	1995		1996		1995		1996	
Cover Crop	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				g m^{-2}			
Santiago Medic	53.0**	21.0	19.5	29.3**	65.7***	70.8**	19.9***	9.4***
Mogul Medic	29.0***	19.5	39.5	57.5	52.5***	51.7***	35.1	41.1***
Red Clover	20.3***	20.5	17.3	27.8**	51.4***	42.4***	12.5***	26.3***
Berseem Clover	29.0***	22.5	-	77.3	46.2***	74.4**	-	56.6**
No Cover	91.0	26.8	30.5	81.8	233.7	123.5	43.0	76.3

Values are significantly different than the no cover control within a column at: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$, with a single degree of freedom F-test.

Table 2. Density and dry weight of summer annual weeds following legume cover crops and no cover control.

	Weed Density				Weed Dry Weight	
	1995		1996		1995	1996
Cover Crop	EL	KBS	EL	KBS		
	no. m^{-2}				g m^{-2}	
Santiago Medic	4.0**	22.5	29.8	5.8	2.2**	4.7
Mogul Medic	4.8	14.0	36.3	15.5	2.4**	12.2
Red Clover	46.5	17.3	10.5**	13.0	2.3	4.5
Berseem Clover	7.8	24.5	-	9.8	2.9	-
No Cover	42.1	18.8	37.8	12.3	8.6	7.9

Values are significantly different than the no cover control within a column at ** $P \leq 0.05$, with a single degree of freedom F-test.

Table 3. Density and dry weight of summer annual weeds with and without legume residue removed.

<table>
<tr><th></th><th></th><th colspan="2">Weed Density</th><th colspan="4">Weed Dry Weight</th></tr>
<tr><th></th><th></th><th>1995</th><th>1996</th><th colspan="2">1995</th><th colspan="2">1996</th></tr>
<tr><th>Cover Crop</th><th></th><th></th><th></th><th>EL</th><th>KBS</th><th>EL</th><th>KBS</th></tr>
<tr><th></th><th></th><th colspan="2">no. m⁻²</th><th colspan="4">g m⁻²</th></tr>
<tr><td>Santiago Medic</td><td>w/o residue</td><td colspan="2">34.1***</td><td colspan="4">8.1***</td></tr>
<tr><td></td><td>w/ residue</td><td colspan="2">15.7</td><td colspan="4">3.2</td></tr>
<tr><td>Mogul Medic</td><td>w/o residue</td><td colspan="2">29.2*</td><td colspan="4">9.8**</td></tr>
<tr><td></td><td>w/ residue</td><td colspan="2">18.4</td><td colspan="4">7.1</td></tr>
<tr><td>Red Clover</td><td>w/o residue</td><td>26.4</td><td>35.3**</td><td>2.1</td><td>1.2</td><td>18.4**</td><td>7.1</td></tr>
<tr><td></td><td>w/ residue</td><td>32.0</td><td>11.8</td><td>2.0</td><td>2.3</td><td>2.2</td><td>6.7</td></tr>
<tr><td>Berseem Clover</td><td>w/o residue</td><td colspan="2">28.2</td><td colspan="4">5.7</td></tr>
<tr><td></td><td>w/ residue</td><td colspan="2">15.3</td><td colspan="4">3.4</td></tr>
</table>

Values are significantly different within a cover species at: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$, with a T test.

Table 4. Perennial weed density and dry weight following legume cover crops and a no cover control just prior to corn planting.

	Weed Density	Weed Dry Weight			
		1995		1996	
Cover Crop		EL	KBS	EL	KBS
	no. m^{-2}	g m^{-2}			
Santiago Medic	12.6	2.3*	1.9***	2.6***	3.2***
Mogul Medic	19.0	6.4**	2.4***	5.4***	10.3
Red Clover	9.8	1.5**	0.1***	2.8***	5.0**
Berseem Clover	13.8	5.5	17.4***	-	6.6**
No Cover	15.8	8.0	8.4	9.9	13.1

Values are significantly different than the no cover control within a column at: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$, with a single degree of freedom F-test. .

Table 5. Perennial weed density and dry weight following cover treatments and no cover control approximaltely 45 days after corn planting.

	Weed Density				Weed Dry Weight			
	1995		1996		1995		1996	
Cover Crop	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				g m^{-2}			
Santiago Medic	5.5*	22.5	5.8*	10.5	1.1	2.9	0.7*	1.1
Mogul Medic	5.3**	14.0	9.3	19.8	0.4	2.7	2.1	4.0*
Red Clover	9.5	17.3	7.8	32.5**	1.9	2.3	1.1*	4.2**
Berseem Clover	13.0	24.5	-	11.8	1.2	3.7	-	1.0
No Cover	10.3	18.8	11.5	16.5	0.8	2.6	4.1	0.8

Values are significantly different than the no cover control within a column at: * $P \leq 0.10$, ** $P \leq 0.05$, with a single degree of freedom F-test.

Table 6. Density and dry weight of perennial weeds with and without legume residue removed.

Cover Crop		Weed Density		Weed Dry Weight	
		1995	1996	1995	1996
		no. m^{-2}		g m^{-2}	
Santiago Medic	w/o residue	10.8***		4.3***	
	w/ residue	7.1		1.0	
Mogul Medic	w/o residue	17.5***		5.5***	
	w/ residue	11.6		1.8	
Red Clover	w/o residue	19.9**		7.2***	
	w/ residue	12.5		1.8	
Berseem Clover	w/o residue	13.0**		4.7***	
	w/ residue	8.7		0.8	

Values are significantly different within a cover species at: ** $P \leq 0.05$, *** $P \leq 0.01$, with a T test. .

Table 7. Density and dry weight of the dominant weed species in the no cover control just prior to corn planting.

	Weed Density				Weed Dry Weight			
	1995		1996		1995		1996	
Weed species	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				g m^{-2}			
Annuals								
Shepherdspurse *Capsella bursa-pastoris*	33.0	0.0	0.0	21.8	53.2	0.0	0.0	32.6
Volunter Wheat *Triticum aestivum* L.	32.8	12.0	18.8	18.0	39.1	39.6	26.8	9.7
Penny Cress *Thlaspi arvensis*	12.8	0.0	0.0	0.0	9.0	0.0	0.0	0.0
Henbit *Lamium amplexicaule*	0.0	11.8	11.3	16.3	0.0	6.2	3.7	3.1
Common Chickweed *Stellaria media*	-	-	-	-	126.7	76.1	12.4	27.1
Perennials								
Broadleaf Plantain *Plantago major* L.	5.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0
Dandelion *Taraxacum officinale*	1.0	2.3	4.3	3.3	5.6	4.8	7.8	3.6
White Clover *Trifolium repens* L.	0.0	3.8	0.0	0.0	0.0	3.7	0.0	0.0
Quackgrass *Elytrigia repens* L.	0.0	0.0	3.8	35.0	0.0	0.0	2.3	7.9

Table 8. Density and dry weight of the dominant weed species in the control 45 days after corn planting.

	Weed Density				Weed Dry Weight			
	1995		1996		1995		1996	
Weed species	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				$g\ m^{-2}$			
Annuals								
Lambsquarters *Chenopodium album* L.	3.8	0.5	0.0	0.8	0.5	0.2	0.0	1.5
Redroot pigweed *Amaranthus retroflexus* L.	34.0	0.0	0.0	1.8	5.2	0.0	0.0	0.1
Purslane *Portulaca oleracea*	0.0	0.0	23.8	5.0	0.0	0.0	7.3	2.5
Smartweed *Polygonum coccineum* Muhl.	0.0	0.0	4.3	0.0	0.0	0.0	3.5	0.0
Foxtail *Setaria faberii* Herm.	4.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Large Crabgrass *Digitaria sanguinalis* L.	0.0	10.8	1.8	4.0	0.0	1.8	0.3	2.3
Smooth Crabgrass *Digitaria ischaemum*	0.0	5.8	0.0	0.0	0.0	0.5	0.0	0.0
Barnyardgrass *Echinochloa crus-galli* L. Beauv.	0.0	0.0	10.5	0.0	0.0	0.0	1.4	0.0
Perennials								
Dandelion *Taraxacum officinale*	1.3	9.3	6.3	6.3	0.1	0.6	0.4	0.1
Plantain *Plantago lanceolata* L.	2.5	0.0	1.0	0.0	0.1	0.0	0.2	0.0
White clover *Trifolium repens* L.	0.0	3.8	0.0	0.0	0.0	8.1	0.0	0.0
Quackgrass *Elytrigia repens* L.	6.0	0.0	0.0	8.5	0.3	0.0	0.0	0.7

Table 9. Soil temperatures at 5 cm depth taken on selected dates following legume cover crops and a no cover control.

Cover Crop	EL				KBS		
	°C						
1995	21 Apr.	15 May	26 May	22 June	11 Apr.	24 Apr.	12 May
Santiago Medic	8.5	21.0	22.2	31.0	10.6	9.4	23.2
Mogul Medic	8.6	21.0	21.6	32.4	10.9	9.0	22.5
Red Clover	7.9	15.6**	18.6**	30.9	11.5	7.8**	15.9***
Berseem Clover	8.3	20.6	22.4	30.0*	11.8	9.9	22.2
No Cover	8.5	20.3	22.2	32.2	11.3	9.3	21.9
	°C						
1996		16 May	22 May	11 June	17 May	31 May	14 June
Santiago Medic	-	16.8	22.2	24.7	18.5	24.4	30.8
Mogul Medic	-	16.7	22.0	24.5	18.1	24.8	30.7
Red Clover	-	12.9***	19.3	24.0	15.6***	23.6	30.6
Berseem Clover	-	-	-	-	18.3	25.1	31.0
No Cover	-	17.0	21.9	24.3	17.9	24.7	30.8

Values are significantly different than the no cover control within year and date at: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$, with a single degree of freedom F-test.

Chapter 3

THE VALUE OF A PARTICIPATORY APPROACH IN SUSTAINABLE AGRICULTURE RESEARCH

ABSTRACT

As we strive to make agriculture more sustainable our approach to research and extension must be redirected in order to effectively support new or broadened goals. Research designed to generate information applicable to a wide range of conditions will be less likely to satisfy economic and ecological needs of individual farms than research which accounts for site specific considerations. Sustainable technologies are not directly transferable from farm to farm and require an integrative process of learning, not commonly needed with more conventional technologies. Participatory strategies have been advocated for conducting research and developing technologies which will lead to more sustainable agricultural systems. In this study, we sought to find evidence that participatory approaches to the generation and dissemination of information and technologies around sustainable agriculture, specifically cover crops, may be more appropriate than conventional methods. A focus group format was employed to discover the opinions and feelings of farmers and knowledge brokers about the generation and communication of sustainable production practices, using cover crops as an example of such practices. Farmers using cover crops, those not using cover crops, and knowledge brokers had similar levels of knowledge about cover crops. Much of the information desired about cover crops by the participants was site specific in nature and fit well with what can be best learned from participatory on-farm research. Farmers using cover crops are learning how to integrate their farms by participating in farmer-led research and

education groups and by utilizing conventional and alternative sources of knowledge. These farmers are aware that sustainable technologies are not directly transferable to their farm, but instead require them to learn how to integrate the characteristics of the technology to the ecological and socioeconomic aspects of their particular operation. Farmers not using cover crops are using conventional sources of knowledge and are not conducting on-farm investigations. They do not appear to have an awareness that sustainable technologies are not directly transferable to their farm. Knowledge brokers are valued as legitimate information sources and/or partners in learning to both groups of farmers. Evidence was found that participatory approaches would be effective in facilitating the generation and dissemination of sustainable agriculture technologies including: a desire by both farmer groups for more farmer-to-farmer interaction indicating an attraction to the participatory learning process, a desire by knowledge brokers for greater skills in facilitating participatory methods, the fact that farmers are currently learning to integrate their farms with participatory approaches.

INTRODUCTION

Consumers and producers of agricultural products have benefited from the expert-user model for the generation and communication of knowledge as practiced by most agricultural institutions in this country. The expert-user model is characterized by a hierarchy in which information moves from the scientist down through extension services to the users, or farmers in this case. This approach has been successful in generating and increasing the use of technologies that farmers can adopt in essentially the same form in which they were developed. For example hybrid seed, fertilizers, and chemical control of pests require less adaptation to specific farm conditions in order to be used effectively.

However, many of the production issues facing farmers today grow out of the interaction of the farm with the surrounding environment. It is necessary to develop appropriate responses to issues such as maintenance of soil quality, loss of nutrients through leaching and other processes, management of manure for maximum benefit and reduced odor drift, and ecological means of controlling weeds. These issues are all specific to site conditions and farmers' resources. In addition to production issues there are influences from off-farm which impact an operation such as; rising land prices, economic pressures from concentration of production, and loss of the surrounding rural community. Public institutions have not traditionally addressed these issues. Nonetheless, recognition of the undesirable consequences brought about by such forces has put pressure on public institutions to support farmers in these areas.

Solutions to these issues may not successfully be developed solely using an expert-user approach. These issues exist over a broad set of conditions yet their management needs to be ecologically, socially and politically sensitive. The expert-user model requires agricultural research to be general in order to be applicable to a wide range of farm conditions. Only in this way is technology transferable. "To be successfully adopted, new alternative production strategies must satisfy the economic and ecological needs of individual farmers" (Gardner, 1990). Research designed to generate information applicable to a wide range of conditions will be less likely to satisfy economic and ecological needs of individual farms than that which includes site specific considerations. In addition to being more site-sensitive, the transfer of information is greater when the end-user is more involved in its development (Chambers, 1983; Roling and Van de Fliert, 1994). In order for researchers and farmers to realize the benefits of participatory methods, multiple knowledge sources must be respected and considered valid when decisions about development are made (Gerber, 1992). Accepting multiple ways of knowing has not been a strong point of the expert-user model.

Participatory strategies have been advocated for generating and communicating information and technologies which will lead to more sustainable agricultural systems (Rocheleau, 1994; Dlott et al. 1994; Roling and van der Fliert, 1994; Doll and Francis, 1992; Gerber, 1992; Gardner, 1990). Though early work in participatory research methods took place in developing countries, an evolution of methods continues in both developing and developed countries. (Rocheleau, 1994; Biggelaar, 1991). In the developed countries advocates of integrated farming systems who desire to link the environmental, social and economic implications of a technology to the process of its development (Dlott et al. 1994; Hesterman and Thorburn, 1994) have brought participatory strategies to the forefront. Participatory methods are being explored in part, because traditional agricultural institutions have not served the needs of farmers interested in alternative methods (Buttel and Youngberg, 1985). One reason for this is that the structure of these institutions limits their ability to address the root issues of sustainability. The reward system for scientists based on publications limits interest in long-range interdisciplinary projects and on-farm research, as does the disciplinary structure of university departments. However, it is research on agricultural systems carried out in an interdisciplinary fashion, with at least some done on-farm, which will result in integrated farming technologies (Buttel and Youngberg, 1985).

In business and industry, the importance of end-user participation and feedback is well established (Plunkett and Rournier, 1991; Senge, 1990). It is through end-user participation in the development process that true needs are discovered and appropriate solutions are devised. The challenge to involve end-users may be greater in agriculture than in other areas since there is a large number of users spread out over a vast area, each with different site variables, including soil, climate, equipment, preferences, and goals.

Participatory methods differ from expert-user methods in the level of users' involvement in the process of generating and disseminating knowledge. When the farmer is involved as a decision-maker, technology is more likely to fit the farm system than the farm system having to fit the technology. This allows for easier incorporation into farm processes when the farmer has participated in the technology's development, they have confidence in their ability to make it work on their farm, as well as to advise or assist other farmers. When technology is developed by researchers alone and handed down to farmers for adoption this is not the case.

Research conducted on working farms will lend itself to increased participation by farmers as well as provide a realistic context in which to evaluate new technologies. Research conducted on-farm can have an advantage over on-station research in areas such as; agronomic and economic evaluation of production systems as they would actually be practiced, and questions which consider the whole farm such as allocation of labor and capital (Lockeretz, 1985). Although on-farm research has advantages, not all important lines of investigation are best developed in this context. More controlled conditions may be required in determining how biological processes work as well as for long-term studies which need to be free from cropping restrictions found on-farm (Rosmann, 1994). Employing on-farm and on-station research in a complementary fashion will make use of their individual strengths. A research program which involves farmers, researchers, and extension personnel will help increase the ability of all to accept multiple ways of knowing.

Participatory methods of research and extension can be employed at the farm and community level. In the simplest case, a farmer may conduct an investigation on his/her farm with assistance from a local knowledge broker (Extension agent or crop consultant). Together they decide what is to be investigated, who will conduct the field operations, and what the results imply for future management decisions. Independently or together they may decide to talk to other farmers about their work or even hold a field day to demonstrate what they have learned. In more involved situations, a knowledge broker would work with a group of farmers where all participants have a decision-making role. Periodic group meetings would provide the opportunity to exchange information, discuss results, plan for the future, and establish kindred relationships with others of like mind. In these meetings the knowledge broker would function more as a group facilitator and a co-learner than as the traditional "expert". In both these situations, farmers have more control over the nature of production information, and in addition, become sources of knowledge to other farmers.

At another level, participatory approaches can be used to influence resource allocation within institutional research arenas. At this level, a diversity of stakeholders including researchers, knowledge brokers, farmers, and perhaps environmental advocates and policy makers (Gardner, 1990) would have significant input towards the following questions: What knowledge is to be pursued and what technology is to be developed? How will the development of the technology be approached ? How will the knowledge and technology be extended? Representatives of these stakeholder communities would serve on decision-making boards at the local, state, and federal levels. They would contribute to the decision-making process by emphasizing values common to the community, thus introducing a social aspect to the pursuit of knowledge. For example, research on meeting crop nutrient needs would consider multiple criteria, going beyond the crop use of nutrients to include crop uptake efficiency, loss to the environment, health implications to farmers and neighbors, evaluation of renewable nutrient sources, and effects on short and long-term profitability. Community members working alongside researchers and policy makers can effectively represent and negotiate these multiple perspectives.

The complex issues that comprise the barriers to sustainability will require that decision makers pursue and embrace many of the outcomes of participatory methods. Nault (1991), from his review of the literature, indicates how participatory methods can address the factors limiting the adoption of sustainable practices (as described by Hill, 1991) (Table 1). The adoption of sustainable practices is limited by a lack of information and the skills by farmers and others to make use of it. Participatory methods produce site-specific information while cultivating a farmers competence with new farming practices and research abilities. The relationships established between farmers and scientists as they work together can create an avenue for institutional change in support of community needs. However, the impact goes well beyond this. Such methods serve to develop the potential and capacities of individuals involved in creating their own future by catalyzing awareness, commitment, motivation, creativity and empowerment. "[Participatory] research should thus be seen as an opportunity for devolving power and establishing local capability for development..." (Biggelaar, 1991). It is our belief that in many cases the increased participation of farmers in the generation and dissemination of production information will increase its relevancy to farmers, its success rate on-farm, and its support for sustainable resource use.

The case is made in the literature that sustainable agriculture technologies are unique and as such, diverge from more conventional technologies in how they can best be developed and disseminated (Roling and van de Fliert, 1994; Nault, 1991; Dlott et al. 1994). To successfully implement sustainable technologies, farmers will need to go through a process of adapting the technology to their conditions. Appropriate use of sustainable technologies will vary considerably with site conditions, will require greater understanding of basic biological processes, are most profitable when approached from a whole system perspective including short and long term goals, and may not be directly connected to farm income. As a result, traditional financiers are often not willing to assist farmers in these technologies. Implementing technologies like integrated weed and insect management and soil stewardship require an expanded knowledge base. This adaptation process is more critical to these technologies than to more conventional technologies such as fertilizer or herbicide use because the learning required is greater. When farmers are involved as partners in learning, the knowledge base is expanded and the relevancy and effectiveness of many areas of research and extension can be increased (Dlott et al. 1994; Ashby, 1986).

In this study, we sought evidence that participatory approaches to the generation and dissemination of sustainable agriculture information and technologies, specifically cover crops, may be more appropriate than conventional methods.

METHODS

In this study we used a focus group format (Krueger, 1988) to discover the opinions and feelings of farmers and knowledge brokers about the generation and communication of sustainable production practices, using cover crops as an example of such practices. In the focus group method, individuals who share a common attribute are gathered for a facilitated discussion on the topic of investigation. The advantage to this group approach is that the interaction among participants often leads to a deeper development of ideas than does a series of one-on-one interviews or a written survey approach.

Three distinct groups were used in this study: Group 1 were farmers currently using cover crops in their farm operation. Group 2 were farmers not currently using cover crops in their farm operation. Group 3 were knowledge brokers, including Extension agents and crop consultants, who serve a variety of farmers, and are known to have some knowledge of and experience with cover crops. Focus group sessions lasted 2 to 2.5 hours. Each session was conducted by a facilitator and a co-facilitator who recorded what was said on a flip chart and audio tape. The facilitator guided the discussion through four main topics: (1) assessment of the group's knowledge about cover crops, (2) types of research and production information desired about cover crops, (3) preferred sources of production information including, but not limited to, cover crops, (4) participants description of current means of technology generation and transfer and response to an alternative participatory approach (Table 2).

Farmers in Group 1 were selected from lists provided by knowledge brokers from around the state. Farmers in Group 2 were selected from lists provided by knowledge brokers and from a Wheat 2000 (Miscellaneous, 1995) data base which provided information on Michigan wheat growers and whether or not they used cover crops. Knowledge brokers in Group 3 were selected based on recommendations from extension specialists or as a result of their involvement with cover crops in the state. All prospective participants were sent a letter of invitation. Within 10 days of sending the letter a follow-up phone call was made inquiring if they would be willing to participate. Those who agreed to attend received a second phone call the day before the focus group session to confirm their attendance.

Data were collected from each group regarding information they would like to have about cover crops. Each group was asked to generate a list of information needs. The list was recorded on a flip-chart. Each participant was asked to prioritize the items on the list using a point system. Points given to each item were added and divided by the total number of points used by the group. Data are presented as a percentage of all points used by each group (Table 3).

RESULTS AND DISCUSSION

Knowledge about Cover Crops

Each group demonstrated knowledge of the potential role and benefits of cover crops. Participants spoke about the use of cover crops for various purposes: soil coverage to reduce erosion, nutrient contribution, management of soil organic matter, weed suppression and soil moisture management. All participants were familiar with the use of red clover frost-seeded into wheat, perhaps the most common cover crop option in grain production in Michigan. Most of the Group 1 participants were using red clover in this way. Farmers in group 2 described some problems they had experienced with this cover crop when trying it in the past: excess residue impaired planting the subsequent crop; access to the field was delayed by the trapping of excess soil moisture; wheat lodged into clover was difficult to harvest and resulted in wheat sprouting. The use of a rye cover crop for soil coverage and moisture management in corn and soybeans was also familiar to both farmer groups. All three groups had a strong sense of the long-term benefits to soil productivity associated with cover crops, but some individuals in all groups were not sure these benefits translated to economic benefits.

Farmers were asked if the use of cover crops increased or decreased risk to their farm operation success. Roughly half of the Group 1 farmers felt there was no attendant risk. One farmer felt they increased the stability of the operation. Another stated that with cover crop use he was "switching risks" since every production choice, be it fertilizer, herbicide, or tillage methods, was associated with some risk. Group 2 farmers felt risks associated with cover crops could be avoided by substituting such practices as fertilizer use or the maintaining of crop residues.

Desired Information about Cover Crops

The information most desired by farmers currently using cover crops included specific benefits provided by each cover crop to a following crop, especially nutrient contribution, more details on long-term soil effects (2- 5 years), and economic information on cover crop use, which was referred to as a short-term effect (Table 3). Similarly, farmers not using cover crops said they would be most influenced to do so by information on short-term nutrient contributions and the long-term effects on soil quality, putting both in relation to their influence on production costs.

Knowledge brokers were asked what information or skills they felt would help them assist farmers in successfully utilizing cover crops. All agreed that information demonstrating the economic benefits of cover crops would be very useful (Table 3). In addition, knowledge of how to maximize nutrient contribution and how to establish and manage various cover crop species was needed. Responses by knowledge brokers reflected the needs stated by farmers and showed their awareness of factors which farmers say influence their decisions about cover crops. Lists of prioritized information needs can be found in Appendix 1.

Responses from the three groups were very similar, indicating both knowledge of cover crops and agreement on how they can be used to benefit the farm system. Why one group of farmers uses them and the other does not is not immediately evident from the responses. Both farmer groups were aware of compelling knowledge about the potential benefits. One farmer not using cover crops felt that to reduce erosion, the use of no-till as well as the use of crops that leave a covering residue both remove the need for cover crops. However, he also admitted that on soils he plows in the fall, where erosion risk is high, he has not considered the use of cover crops. One farmer who uses cover crops stated that, unlike himself, "Most farmers are not of the philosophical bent that cover crops are good". This implies that for some farmers technical and economic information may not be the major factor in deciding to use cover crops.

Sources of Information for Crop production and Cover Crop Use.

Both groups of farmers cited similar sources of production information including farm magazines, extension personnel, university or industry bulletins, on-farm demonstrations and field days, as well as talking to other farmers. These sources provided ideas and specific information which they utilized when trying new things on their farm. Both farmer groups felt that obtaining cover crop information from the sources already supplying other production information would be best. For example, an article on cover crops in a currently used magazine is more welcome than a separate publication, seeing a cover crop demonstration at a field day with other demonstrations is preferred to a separate cover crop demonstration. Farmers not using cover crops felt this would enable them to get exposure to information they would not ordinarily pursue.

The relative usefulness of the cited sources varied. For example, it was felt that extension agents know more about the dominant farming issues of their county and may not be up on particular stewardship or conservation-type practices that are not common to that area. Farm magazines, on the other hand, provide an array of information with periodic articles on stewardship practices including cover crops. Most farmers felt having someone knowledgeable with which to talk was most desirable.

Farmers who use cover crops cited specific alternative sources for stewardship/cover crop information because it was usually not available from more mainstream sources. If it had been available from mainstream sources, such as extension specialists and agents, these farmers would welcome it and consider it credible. The Michigan Agricultural Stewardship Association (MASA), a farmer-led research and education organization, provides funding for farmers to conduct on-farm research on alternative agricultural practices including cover crops. The results are presented at field days and annual meetings, in newsletters and an annual research summary booklet. MASA was cited as a good source of information, yet some questioned its reliability because research presented was not always replicated and often conducted for only one growing season. Farmers not using cover crops did not cite MASA as a source of information. When asked if they were aware of MASA, farmers not using cover crops recalled seeing a MASA annual research report which came as part of a Farm Bureau newsletter. A recent Cover Crop Symposium held by University Extension at Kellogg Biological Station was cited as a very valuable source, not so much for formal presentation of information, but for the opportunity to interact with other farmers in group discussion and during breaks in a facilitated learning context.

Along this same line, farmers who use cover crops were asked what they would suggest a farmer do in beginning the use of cover crops. Most respondents pointed to the importance of contact with someone knowledgeable (either an extension agent or farmer), coupled with experimentation on their farm.

Generation and Transfer of Cover Crop Information

Current Generation and Transfer of Information

All groups were asked to describe their perceptions and experiences of information and technology generation and flow as it currently exists. Both farmer groups said information usually flows to them from the university via the extension service, in a one-way direction. These two groups said information from extension was valuable and helped in making decisions for change on the farm, yet they found the agent hard to contact. Written information sent by the agents was most accessible. Farmers who use cover crops stated that they felt like receivers of information rather than participants in a process of learning where their input is incorporated. One farmer stated he is "not being served by the system" because material presented at extension functions is already familiar to him. Another felt extension should be "more receptive to innovative ideas". Farmers who don't use cover crops also expressed the feeling of receivership and the desire for more farmer-to-farmer interaction facilitated by extension.

In sum, farmers in the focus groups experienced university representatives as experts who provide information and not as partners in problem-solving and generation of information. Although most found extension valuable, both farmer groups would welcome more dialogue and interaction with knowledge brokers and other farmers. In fact, all three groups expressed their pleasure with the focus group format used in this study precisely because it provided a context for farmer-to-farmer contact (or broker to broker contact) wherein their input was sought and valued.

Participatory Approach to Information Generation

All three groups were presented with a general model of information/technology generation and dissemination in which farmers participate as co-learners with knowledge brokers or scientists. In this model, farmers have significant input regarding what is studied, how it is researched, and how results are reviewed and interpreted and disseminated. Knowledge brokers said they were familiar with two technologies being developed in this manner, narrow row soybeans and Global Positioning Systems (GPS). With GPS, Extension is working on-farm to develop the skills of farmers and knowledge brokers. The relationship between farmers and knowledge brokers has been enhanced as a result of their cooperative work with this new and exploratory technology. The fact that GPS is unfamiliar to both parties affords them the experience of learning together, while the creativity and ideas that come from both are given value.

Farmers in the two groups responded differently to the presentation of the participatory model. Farmers who use cover crops liked the idea but not all felt they had the time to do research and farm. Those who do take the time to research would welcome the partnership with knowledge brokers and their resources. The full concept of a participatory approach was difficult to communicate to both farmer groups, especially the non-cover crop users. This group kept drawing a strong parallel to on-farm demonstration where the farmer may or may not put out the study and the topic is decided by the knowledge broker or input company. In this process the technology is already developed and the on-farm work is simply a demonstration for area farmers. This is a tried and true method from the diffusion-adoption approach and usually does not create a co-learning relationship. Farmers not using cover crops felt they may not understand the scientific aspects of research and therefore have little to contribute. They felt demonstrations were very useful, but were not willing to take the time to carry them out and showed little interest in having input on decisions regarding the demonstrations.

Knowledge brokers (Group 3) and cover crops users (Group 1) expressed the desire for more resources directed toward participatory approaches. They both felt these would complement the current learning strategies and would increase both the relevancy and use of agricultural research results. Knowledge brokers wanted training in how to work with farmers so that they could consciously shift field demonstrations to a more co-learning process.

CONCLUSIONS

Farmers in this study who are using cover crops realized that it is their responsibility to establish environmentally sound farming systems which utilize practices such as reduced tillage, crop rotation, cover crops, and site-specific rates for nutrients and chemicals. Until recently, they have not found conventional sources willing or able to provide knowledge which will support these efforts. From their on-farm work, these farmers are aware that sustainable technologies are not directly transferable to their farm, but instead require them to learn how to integrate the characteristics of the technology to the ecological and socioeconomic aspects of their particular operation. These farmers are learning how to integrate their farms by participating in farmer-led research and education groups, which accelerates the learning process, and by utilizing conventional and alternative sources of knowledge to carry out on-farm investigations. In each case, knowledge brokers are valued as legitimate information sources and/or partners in learning, depending on the orientation of the individual broker.

Farmers in this study who are not using sustainable agriculture technologies have an appreciation for the site specific nature of many farming practices. For example, they made a distinction between soils that are appropriate for no-tillage verses those that are not. However, they do not appear to have an awareness that sustainable technologies are not directly transferable to their farm and would require an integrative process beyond that of conventional technologies. Farmers in this group were somewhat familiar with cover crop technology and were quick to cite problems that could arise with their use. They are using conventional sources of knowledge and are not conducting on-farm investigations. In addition, they were not familiar with participatory approaches and did not see an advantage to them when presented with a participatory model. However, they did express a desire for more farmer-to-farmer interaction indicating an attraction to participatory learning process.

It is not clear from this limited study the extent to which participatory methods will assist in the generation and dissemination of sustainable agriculture technologies, as suggested in the literature. Participatory approaches are relatively new, not only to farmers but to researchers and knowledge brokers as well. Agriculture is a field that has traditionally generated and disseminated knowledge using only the expert-user model. Farmers are accustomed to being receivers of information in this system. It is therefore not surprising that the communication of the participatory approach in general is still unclear as well as under what conditions it might be useful.

As a result of our focus group responses, we predict the greater use of participatory methods would indeed increase the relevancy of research and use of sustainable agriculture technologies. There is evidence that participatory approaches, if not essential, may be extremely effective in facilitating the generation and dissemination of sustainable agriculture technologies. First, the minimal use of cover crops by farmers in Michigan (estimated to be between 1 and 5%) indicates that conventional methods of information transfer have not facilitated their use, even though their utility has been demonstrated many times over. Second, both farmer groups desired more farmer-to-farmer contact and more contact with knowledge brokers. Third, knowledge brokers desire greater skills in participatory methods. Fourth, the growing popularity of farmer-led research and education organizations, which in most cases have strong partnerships with individual university scientists or extension agents, demonstrates the effectiveness of participatory methods in developing and disseminating information.

FUTURE RESEARCH

There are several research approaches that have the potential to further elucidate answers to the question being posed in this study; namely, is a participatory research approach appropriate and/or essential for the development and adoption of sustainable agriculture technologies? These approaches includes:

- Disseminating knowledge regarding a particular sustainable agriculture technology to separate but similar groups of farmers with varying levels of end user participation. The effectiveness of each level would be determined based on the extent to which farmers in each group pursue the use of the technology.

- Initiating on-farm research with several groups of farmers allowing for different levels of farmer involvement in each group. Observations would be made regarding the amount of learning about as well as increased use of the technology.

- Initiating ongoing working groups in separate communities on a common challenge or emerging technology. These working groups would be asked to create solutions which could be tested and further developed on-farm. Before and after surveys and interviews would be used to determine the effectiveness of the working group in informing and increasing the generation and adoption of sustainable agriculture technologies.

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Table 1. Comparison of outcomes of participatory research with factors limiting the adoption of sustainable agriculture practices.

FACTORS LIMITING THE ADOPTION OF SUSTAINABLE PRACTICES	OUTCOMES OF PARTICIPATORY RESEARCH
· Lack of sufficient information	· Site-specific information
· Lack of site-specific skills	· Competence with new farming practices developed on site Ability to conduct own research
· Limited institutional support	· Cooperation between farmers and scientists creates support
· No common vision to guide development process	· Commitment, motivation and creativity which can provide the groundwork for a common vision
· Awareness of the non-sustainable nature of conventional agriculture practices	· Awareness
· Individuals and communities empowered to change	· Empowerment and confidence
· Values related to sustainability	· Exposure to values held by others

Adapted from Nault (1991).

Table 2. Questions presented for discussion during the focus group interviews.

Knowledge assessment:

G1.[1]
- How are you using cover crops on your farm?
- What is your motivation to use cover crops?
- Do you feel cover crops have long term benefits?
What are these long term benefits?
- Would you say that the use of cover crops increases or decreases the risk of a farm operation?

G2.
- Have you used cover crops in the past, and if so in what way?
- What other reasons are there for using cover crops?
- Do you feel cover crops have long term benefits?
  What are these long term benefits?
- If you were to begin using cover crops on your farm, what contributions or benefits would you be looking for?
- Would you say that the use of cover crops increases or decreases the risk of a farm operation?

G3.
- What percentage of farmers in your area use cover crops and what do you think are their main motivations for using them?
- In your opinion, why don't more farmers use cover crops?
- Do you think that most farm advisors feel knowledgeable enough about cover crops to assist farmers in using them successfully?

Types of research results and production information desired:

G1.
- What research results or production information about cover crops would you like to have?
  Do you think most farmers who use cover crops share your feeling on this?
- How would you like to get research results and production information? In other words how would you like to access this information?
- Is there any difference between how you want access to cover crop information and other production information?

G2.
- What research results or production information about cover crops would you need in order to begin using them on your farm?
  Do you think most farmers who are not using cover crops feel the same way?
- How would you like to get research results and production information? In other words how would you like to access this information?
- Is there any difference between how you want access to cover crop information and other production information?

G3.
- What research results, production information or skills do you need in order to continue assisting farmers in successfully utilizing cover crops?
  Do you think this is true for most farm advisors?
- Are there any skills you would like to have that are non-technical which would assist you in working with farmers about cover crops?
- Do you feel that training in working with groups would be beneficial?
- How would you like to get research results and production information? In other words how would you like to access this information?
- Is there any difference between how you want access to cover crop information and other production information?

Table 2. (continued)

Sources of Information:

G1. · Think back to when you started using cover crops.
What was your original motivation?
How did you learn to successfully use cover crops?
Where did you get the practical information about cover crops?
· Where or from whom do you get most of your information on production practices currently?
· Do these sources provide information on cover crops and other stewardship or conservation practices? Which ones?
· Is this where you get most of your cover crop information?
· Is the information consistent among sources?
· If a farmer was interested in using cover crops and was not currently doing so, how would you suggest they proceed in order to be successful?

G2. · Think back across the years that you have been farming. How did you learn to farm the way you do?
Was there any individual who really assisted you?
· Where or from whom do you get most of your information on production practices currently?
· How do you use this information? For example, after you read an article what is the next step for you?
· Do these sources provide information on cover crops?
What about other stewardship or conservation practices?
· Are you familiar with Michigan Agricultural Stewardship Associations (MASA) and the Innovative Farmers of Huron County?
Do you feel the information they put out is credible?

G3. · Is there sufficient information on cover crops available to you?
· Where do you get most of your information on cover crops?
· Is the information consistent among sources?

Current generation and transfer of information:

G1 and G2.
· How would you describe the movement of agricultural production information between the university, agricultural extension, and the farmer?
· Do you feel like a receiver or producer of information or both?
· How could this process be more useful to you?

G3. · How would you describe the movement of agricultural production information between the university, agricultural extension, and the farmer?
· How do you identify current or potential concerns that are important to spend time on?
· Do you feel these are effective approaches to meeting farmers needs?
How could the process become more useful to farmers?
· In your experience, is working with farmers to facilitate cover crop use any different than working with them on any other topic? In what ways?

Participatory approach to generation and transfer of information:

I would now like to present to you a simple model where farmers participate in the process of generating information and extending it to others. In this model farmers and farm

Table 2. (continued)

advisors (Extension agents, specialists, and others) work together to generate the information they require. Each
bring different skills to the process. In this approach farmers have a major influence on what is researched. They work with researchers to design an approach to generating the needed information. A significant amount of research would be done on working farms. Together farmers and researchers review the progress of the study and interpret the results.

G1, G2 and G3.
- Do you think this would be an effective approach to providing information about cover crops which would be useful to farmers?
- What might be some of the advantages and drawbacks of this approach?
- Have any of you had any experience with this type of on-farm research?
  - How do you feel about it?
  - Would you do it again?

G3.
- Would you like the university to provide more support for you in carrying out participatory research?
  - What type of support would you like?

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[1] G1 is the group of farmers using cover crops, G2 is the group not using cover crops, and G3 is the group of knowledge brokers.

Table 3. Desired information about cover crops generated by each focus group.

Information Desired	Farmers [1] using cover crops	Farmers not using cover crops	Knowledge Brokers
	%		
Long term effects (3-10 years) on soil productivity and farm profitability	20	25	-
Nutrient benefits to a following crop by each cover crop option.	25	31	19
Short term costs and effect on farm income.	14	-	21
Field demonstrations of covers in cropping systems.	11	-	-
Specific cover strategies for specific rotations.	11	10	-
System effects from a cover crop compared to previous crop residue.	6	-	-
Appropriate covers and management information for use in no-till corn.	6	13	-
Methods and timing for killing covers.	-	-	13
Appropriate establishment methods.	-	8	11
Potential problems associated with covers.	4	8	10
Environmental benefits associated with covers	-	-	9
Sources for cover seed	-	-	8
Weed suppression potential and compatibility with herbicides.	1	5	6
Alternate uses of covers	-	-	3

[1] Values are the percentage of the total points within each group given to each information need.

APPENDIX

Table A.1. Density of the all weed species prior to burndown application in 1995 at EL and KBS.

	Weed Density				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
			no. m^{-2}		
EL					
Capsella bursa-pastoris	13.3	3.4	4.0	0.7	33.0
Triticum aestivum L.	18.5	15.8	15.0	15.5	35.8
Thlaspi arvensis	8.8	5.8	0.3	0.0	12.8
Ranuculas allegheniensis	8.3	2.0	0.8	8.5	5.3
Poa annua L.	4.3	1.8	0.3	4.3	4.3
Plantago major L.	1.0	2.3	0.8	0.0	5.0
Taraxacum officinale	2.5	0.5	0.5	1.3	1.0
Lychnis alba Mill.	1.0	0.5	0.3	0.3	0.8
KBS					
Lamium amplexicaule	8.8	9.0	6.8	10.3	11.8
Triticum aestivum	11.8	9.0	13.8	10.0	12.0
Poa annua L.	0.3	1.3	0.0	2.0	2.8
Taraxacum officinale	1.3	2.5	0.5	0.5	2.3
Erigeron strigosus Muhl.	0.3	0.3	0.0	0.3	0.3
Trifolium repens L.	1.3	1.0	0.0	9.5	3.8
Stellaria media	-	-	-	-	-
Plantago major L.	0.0	0.0	0.0	0.8	0.0
Rumex crispus L.	0.3	0.0	0.00	0.5	0.0

Table A.2. Dry weight of the all weed species prior to burndown application in 1995 at EL and KBS.

	Weed Dry Weight				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	$g\ m^{-2}$				
EL					
Capsella bursa-pastoris	7.8	2.6	1.8	0.8	53.2
Triticum aestivum L.	6.1	3.6	11.2	4.1	39.1
Thlaspi arvensis	4.9	236	0.0	0.0	9.0
Ranuculas allegheniensis	2.9	0.3	0.8	2.0	2.6
Poa annua	1.7	1.9	0.0	2.0	3.2
Plantago major	0.1	0.2	0.0	3.9	1.4
Taraxacum officinale	1.4	0.1	0.1	1.0	5.6
Lychnis alba Mill.	0.85	0.1	0.0	0.0	0.6
Rumex crispus	0.0	0.1	1.4	0.6	0.4
Stellaria media	42.7	41.4	37.6	37.4	126.7
KBS					
Lamium amplexicaule	2.6	3.2	2.5	10.0	6.2
Triticum aestivum .	28.6	15.9	28.3	18.7	39.6
Poa annua L.	0.0	0.3	0.0	0.1	1.4
Taraxacum officinale	1.1	1.7	0.1	3.6	4.8
Erigeron strigosus Muhl.	0.0	0.0	0.	0.0	0.3
Trifolium repens L.	0.8	0.7	0.0	13.7	3.7
Stellaria media	39.5	32.3	11.8	45.6	76.1
Plantago major L.	0.0	0.0	0.0	0.1	0.0
Rumex obtusifolius	0.0	0.0	0.0	0.1	0.0

Table A.3. Density and of the all weed species prior to burndown application in 1996 at EL and KBS.

	Weed Density				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	no. m^{-2}				
EL					
Agropyron repens L.	2.0	2.5	0.3	-	3.8
Triticum aestivum L.	18.5	32.3	12.8	-	18.8
Taraxacum officinale	5.0	8.0	5.0	-	4.3
Lamim amplexicaule	0.8	7.0	4.3	-	11.3
Dactylis glomerata	0.0	0.5	0.0	-	0.0
Sonchus oleraceus	0.0	0.0	0.3	-	0.0
Beteroa incana L. DC.	0.3	0.3	0.0	-	0.5
KBS					
Agropyron repens L.	34.3	52.3	26.8	26.5	35.0
Triticum aestivum L.	3.5	25.3	5.8	32.3	18.0
Erigeron sp.	3.5	1.5	0.0	1.0	1.3
Taraxacum officinale	1.3	3.3	1.3	0.8	3.3
Capsella bursa-pastoris	16.8	16.0	20.5	21.3	21.8
mouse ear cress	2.3	9.3	0.5	10.3	24.5
Dactylis glomerata	0.0	0.5	0.0	0.0-	0.0
Sonchus oleraceus	0.0	0.0	0.3	0.0-	0.0
Beteroa incana L. DC.	0.3	0.3	0.0	0.0-	0.5
Dactylis glomerata	0.5	1.3	0.0	1.3	0.0
Lamium amplexicaule	3.3	5.5	1.0	12.5	16.3
Rumex obtusifolius L.	0.3	1.0	3.5	0.0	0.8

Table A.4. Dry weight of the all weed species prior to burndown application in 1996 at EL and KBS.

Weed species	Weed Dry Weight				
	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
			$g\ m^{-2}$		
EL					
Agropyron repens L.	0.8	0.6	0.1	-	2.3
Triticum aestivum L.	12.8	27.6	10.1	-	26.8
Taraxacum officinale	1.8	4.8	2.7	-	7.6
Lamium amplexicaule	0.0	0.8	0.5	-	3.7
Dactylis glomerata	0.0	0.1	0.0	-	0.0
Sonchus oleracea	0.0	0.0	0.7	-	0.0
Beteroa incana L. DC.	0.0	0.0	0.0	-	0.2
Stellaria media	7.1	6.7	1.3	-	12.4
KBS					
Agropyron repens L.	2.6	8.2	2.8	5.7	7.9
Triticum aestivum L.	0.4	3.9	1.3	8.1	9.7
Erigeron sp.	0.1	0.1	0.0	0.1	0.5
Taraxacum officinale	0.6	1.8	0.8	0.9	3.6
Capsella bursa-pastoris	6.8	22.2	21.2	30.3	32.6
*mouse ear cress	0.2	0.6	0.2	1.1	3.7
Dactylis glomerata	0.1	0.4	0.5	2.0	3.1
Lamium amplexicaule	0.1	0.4	0.5	2.0	3.1
Rumex obtusifolius	0.3	1.0	3.5	0.0	0.8
Stellaria media	1.8	13.9	3.1	15.1	27.1

Table A.5 . Density and of the all weed species prior to postemergence application in 1995 at EL and KBS.

	Weed Density				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	no. m^{-2}				
EL					
Setaria faberii Herrm.	1.5	2.8	2.3	0.8	4.3
Agropyron repens L.	1.8	2.0	3.5	2.0	6.0
Chenopodium album L..	1.8	2.0	3.5	2.0	6.0
Plantago major L.	2.3	2.5	0.8	2.0	2.5
Taraxacum officinale	0.8	0.8	1.3	0.5	1.3
Amaranthus retroflexus	0.8	3.0	31.3	2.5	34.0
Rumex acetosella L.	0.8	0.0	0.3	4.0	0.5
Cyperus esculentus L.	0.0	0.0	0.5	4.5	0.0
Lychnis alba Mill.	0.0	0.0	0.3	0.0	0.0
KBS					
Digitaria sanguinalis L.	14.0	8.8	12.8	15.3	10.8
Digitaria ischaemum	4.3	0.5	4.3	3.0	5.8
Portulaca oleracea	1.8	0.0	0.0	1.5	0.0
Taraxacum officinale	6.8	9.8	0.5	5.3	9.3
Mollugo verticillata L.	1.3	0.5	0.3	3.8	1.8
Amaranthus retroflexus L.	1.0	4.0	0.0	0.3	0.0
Chenopodium album	0.3	0.3	0.0	0.8	0.5
Trifolium repens L.	0.5	0.3	0.0	0.0	3.8

Table A.6 . Dry weight and of the all weed species prior to postemergence application in 1995 at EL and KBS.

	Weed Dry Weight				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	$g\ m^{-2}$				
EL					
Setaria faberii Herrm.	0.1	0.1	0.1	0.1	0.2
Agropyron repens L.	1.0	0.7	0.6	0.5	0.3
Chenopodium album L.	0.3	0.2	0.9	1.1	0.5
Plantago major L.	0.1	0.1	0.0	0.1	0.1
Taraxacum officinale	0.1	0.1	0.1	0.1	0.1
Amaranthus retroflexus	0.1	1.1	1.0	0.7	5.2
Rumex acetosella L.	0.1	0.0	0.0	0.1	0.0
Cyperus esculentus L.	0.0	0.0	0.0	0.6	0.0
Lychnis alba Mill.	0.0	0.0	0.0	0.0	0.0
KBS					
Digitaria sanguinalis L.	2.2	1.3	2.0	2.9	1.8
Digitaria ischaemum	0.5	0.1	0.3	0.3	0.5
Portulaca oleracea	0.0	0.0	0.0	0.4	0.0
Taraxacum officinale	1.2	0.7	0.2	0.2	0.6
Mollugo verticillata L.	0.0	0.0	0.0	0.0	0.1
Amaranthus retroflexus L.	0.1	1.1	0.0	0.0	0.0
Chenopodium album	0.0	0.2	0.0	0.1	0.2
Trifolium repens L.	0.0	0.0	0.0	0.0	8.1

Table A.7 . Density and of the all weed species prior to postemergence application in 1996 at EL and KBS.

	Weed Density				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	no. m^{-2}				
EL					
Portulaca oleracea	16.3	23.3	4.8	-	23.8
Polygonum coccineum Muhl.	1.5	3.3	2.0	-	4.3
Taraxacum officinale	3.8	3.8	5.5	-	6.3
Digitaria sanguinalis	3.8	3.8	5.5	-	6.3
Echinochloa crus-galli L. Beauv.	8.8	9.5	3.3	-	10.5
Setaria lutescens	1.0	0.5	0.3	-	0.0
Plantago major L.	0.3	1.8	0.0	-	1.0
Agropyron repens L.	0.0	0.5	0.3	-	0.0
Panicum dicotomiflorum	0.0	0.0	0.0	-	1.8
Amaranthus retroflexus	0.0	0.3	0.3	-	0.0
Rumex obtusiflolus L.	0.3	0.0	0.0	-	0.0
KBS					
Chenopodium album	0.5	2.3	0.3	0.8	0.8
Taraxacum officinale	1.0	5.5	1.8	6.3	6.3
Plantago major L.	0.3	0.0	0.0	0.0	0.0
Digitaria sanguinalis L.	1.3	4.5	4.0	2.5	4.0
Dactylis glomerata	0.8	0.8	0.8	0.8	1.8
Panicum dichotomiflorum	2.3	1.5	0.8	0.3	0.8
Portulaca oleracea	1.0	0.0	1.3	1.8	5.0
Rumex crispus L.	0.3	0.3	3.0	0.0	0.0
Amaranthus retroflexus L.	0.8	7.3	6.8	4.5	1.8
Agropyron repens L.	8.3	13.3	27.0	4.8	8.5

Table A.8 . Dry weight and of the all weed species prior to postemergence application in 1996 at EL and KBS.

	Weed Dry Weight				
Weed species	Santiago Medic	Mogul Medic	Red Clover	Berseem Clover	No Cover
	g m^{-2}				
EL					
Portulaca oleracea	5.4	16.6	1.1	-	7.3
Polygonum coccineum Muhl.	0.5	1.6	0.7	-	3.5
Taraxacum officinale	0.2	0.2	0.2	-	0.4
Digitaria sanguinalis L.	0.4	0.1	0.2	-	0.3
Echinochloa crus-galli L. Beauv.	0.8	0.8	0.3	-	1.4
Setaria lutescens	0.3	0.1	0.3	-	0.0
Plantago major L.	0.0	0.4	0.0	-	0.2
Agropyron repens L.	0.0	0.1	0.1	-	0.0
Panicum dichotomiflorum	0.0	0.0	0.0	-	0.3
Amaranthus retroflexus L.	0.0	0.3	0.3	-	0.0
Rumex obtusifolius L.	0.0	0.0	0.0	-	0.0
KBS					
Chenopodium album	0.5	2.3	0.3	0.8	0.8
Taraxacum officinale	0.0	0.1	0.1	0.1	0.1
Plantago lanceolata L.	0.0	0.0	0.0	0.0	0.0
Digitaria sanguinalis L..	1.3	1.4	2.9	2.8	2.3
Dactylis glomerata	0.0	0.1	0.0	0.0	0.1
Panicum dicotomiflorum	0.3	0.3	0.0	0.0	0.2
Portulaca oleracea	0.2	0.0	1.5	0.2	2.5
Rumex crispus L.	0.0	0.2	0.1	0.0	0.0
Amaranthus retroflexus L.	0.4	0.6	1.8	0.6	0.0
Agropyron repens L.	1.0	3.7	4.0	0.9	0.7