Published September, 1997

Effect of Annual Medic Smother Plants on Weed Control and Yield in Corn

Robert L. De Haan,* Craig C. Sheaffer, and Donald K. Barnes

ABSTRACT

Using spring-seeded smother plants for weed control could reduce the environmental impact of corn (*Zea mays* L.) production. Research was conducted to determine whether currently available medic (*Medicago* spp.) cultivars are adapted for use as smother plants in corn. In field experiments in 1992 at Becker and Rosemount, MN, *Medicago scutellata* (L.) Mill. cv. Sava and Kelson were interseeded with corn at 0, 85, 260, or 775 seeds m^{-2}. In 1993, Sava and Kelson, along with *M. polymorpha* L. cv. Santiago and *M. lupulina* L. cv. George, were interseeded with corn at 260 seeds m^{-2} and N fertilizer was applied at 0, 84 (56 at Rosemount), or 168 kg ha^{-1}. Land equivalent ratios for corn and medic intercrops grown in 1992 were not > 1, indicating that corn and medics competed strongly for resources. Medics seeded with corn at a rate high enough to consistently suppress weeds (260 seeds m^{-2}) reduced weed dry weight 14 wk after corn emergence by 69% at Becker and by 41% at Rosemount compared with monoculture corn. The same seeding rate reduced corn grain yield in weed-free plots by 21% at Becker and 15% at Rosemount compared with monoculture yields. In 1993, medic smother plants reduced weed dry weight more when grown in the 0 kg ha^{-1} N plots than in the 168 kg ha^{-1} N plots. Corn yield losses, however, were less severe in the 168 kg ha^{-1} N treatments than with 0 N. Annual medics managed as smother plants in corn effectively reduced weed biomass; however, additional research is needed to identify medic genotypes and smother plant management systems that reduce corn yields less than those we evaluated, and that provide more consistent weed suppression across environments..

SMOTHER PLANTS are specialized cover or mulch species selected to suppress weeds without reducing main crop yield (De Haan et al., 1994). Incorporation of spring-seeded smother plants into corn production systems in the U.S. Upper Midwest could substantially reduce the impact of agricultural production on environmental quality. Smother plants have the potential to suppress weed growth (Ateh and Doll, 1996; De Haan et al., 1994), increase soil water infiltration (Bruce et al., 1992), decrease soil erosion (Cripps and Bates, 1993), contribute N to the main crop (Corak et al., 1991; Decker et al., 1994; Maskina et al., 1993), and reduce economic risk (Hanson et al., 1993). Weeds in corn are typically controlled by a combination of tillage and herbicide inputs. Tillage reduces soil surface residue and increases the risk of soil erosion, while herbicides can contaminate water resources. A smother plant capable of effectively suppressing weedy plant species would give producers a much needed alternative weed control method.

Previous research investigating the possibility of biological weed control through plant interference has focused on the use of winter annual or perennial plant species sown in the fall and suppressed or killed with a herbicide application or mechanical disturbance in the spring (Curran et al., 1994; Eadie et al., 1992; Eberlein et al., 1992; Echtenkamp and Moomaw, 1989; Enache and Ilnicki, 1990; Fischer and Burrill, 1993; Grubinger and Minotti, 1990; Hoffman et al., 1993; Johnson et al., 1993; Kumwenda et al., 1993; Mohler, 1991; Teasdale, 1993; Tollenaar et al., 1993; Wilkins and Bellinder, 1996; Yenish et al., 1996). Species evaluated include alfalfa (*Medicago sativa* L.), Austrian winter pea [*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir.], barley (*Hordeum vulgare* L.), Chewing's fescue (*Festuca rubra* L.), crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth), ladino clover (*Trifolium repens* L.), subterranean clover (*Trifolium subterraneum* L.), white clover (*Trifolium repens* L.), winter rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.). Hairy vetch, ladino clover, subterranean clover, and white clover show promise in the central USA, but none of these species is consistently winterhardy in the Upper Midwest, and spring growth of these species can deplete soil water resources. In addition, all of the species investigated, except subterranean clover, require chemical or mechanical suppression to limit their competitive effects on corn.

Spring-seeded annual smother plants are an alternative method for integrating cover crop species into corn production systems, and they may be better adapted to use in the Upper Midwest than are winter annual or perennial plant species. Nitrogen and biomass accumulation would be lower with spring-seeded species than with winter annuals or perennials seeded in the fall (Stute and Posner, 1993), and erosion control in early spring would be less effective, but weed suppression could be comparable (Ateh and Doll, 1996; De Haan et al., 1994), and sod suppression would not be necessary if the plants were relatively small and short-lived.

The feasibility of short-term spring-seeded smother plants is supported by plant competition research. Studies indicate that the presence of weeds for the first 2 to 8 wk after corn emergence may not be detrimental to crop yield, depending on the weed species present, weed population density, soil fertility and moisture availability, and the corn cultivar used (Bunting and Ludwig, 1964; Hall et al., 1992; Knake and Slife, 1969; Nieto et al., 1968; Thomas and Allison, 1975; Zimdahl, 1988). A spring-seeded smother plant may be able to be grown with corn for a similar period of time without reducing crop yield. Previous research also indicates that weeds emerging 3 to 6 wk after corn do not reduce corn yield (Hall et al., 1992; Knake and Slife, 1965; Thomas and Allison, 1975). Smother plant suppression of weeds for the first 4 wk of the growing season may therefore prevent weeds from competing effectively with corn.

R.L. De Haan, Agriculture Dep., Dordt College, Sioux Center, IA 51250; C.C. Sheaffer, Dep. of Agronomy and Plant Genetics, and D.K. Barnes (retired), USDA-ARS, Univ. of Minnesota, St. Paul, MN 55108. Published as Minn. Agric. Exp. Stn. Scientific Journal Series Paper no. 22 462. Received 8 July 1996. *Corresponding author (rdehaan@dordt.edu).

Published in Agron. J. 89:813–821 (1997).

Abbreviations: LER, land equivalent ratio.

Annual medics such as *M. polymorpha* and *M. scutellata* are native to regions surrounding the Mediterranean Sea, where they grow as winter annuals. In the mid-1800s, annual medics were introduced into the USA as forage crops, and they have become naturalized in parts of the South and Southwest; for the past 50 yr, however, annual medics have been virtually ignored by agricultural researchers and producers in the USA. Annual medics were also introduced into Australia where they have become an important crop, and several cultivars have been released for forage use.

Annual medics have the potential to perform well when grown as spring-seeded smother plants in corn. They have a wide range of growth habits, and many have prolific seed production, resistance to insect pests, good forage quality, and high dry matter yields (Zhu et al., 1996). In addition, research by Welty et al. (1988) indicates that annual medics can substantially increase soil NO_3–N content.

Annual medics have not been evaluated as smother crops in any agronomic system in the USA. Our objective was to evaluate the performance of several annual medic cultivars when used as smother plants in corn and determine: (i) resource competition between corn and annual medics, (ii) the effects of annual medic cultivars and seeding rates on weed dry weight and corn development, and (iii) the influence of N fertilization on the competitive interactions among corn, annual medics, and weeds.

MATERIALS AND METHODS

Field experiments were conducted in Minnesota during 1992 and 1993 at the Becker Sand Plains Agricultural Experimental Station and at the Rosemount Agricultural Experiment Station. Soil at Becker was a Hubbard loamy sand (sandy, mixed Udorthentic Haploboroll) and soil at Rosemount was a Waukegan silt loam (fine-silty, mixed, mesic Typic Hapludoll). Soil pH was 6.1 and 6.6 at Becker and 6.5 and 6.8 at Rosemount in 1992 and 1993, respectively. Soil organic matter averaged 1.7% at Becker and 2.2% at Rosemount.

The experimental site at Becker was moldboard plowed in the spring and field cultivated before planting. The Rosemount site was chisel plowed in the fall and field cultivated in the spring. Corn was seeded in 76-cm-wide rows using a four-row corn planter. Medics were immediately interseeded into corn in 15-cm-wide rows at a depth of 0.5 to 1 cm, using a shoe-type planter with press wheels (Wintersteiger GmbH, Ried, Austria). Annual medic seeds were inoculated before planting with medic-specific inoculum (LiphaTech, Milwaukee, WI).

Weeds in weed-free plots were controlled by a preplant incorporated application of Eradicaine [EPTC (*S*-ethyl dipropylcarbamothioate) + R-25788 plant protectant (*N,N*-diallyl-2,2-dichloracetamide)] herbicide at 3.75 kg a.i. ha^{-1}. Eradicaine controlled most annual grass and broadleaf weeds and was not phytotoxic to annual medics. Weed-free plots were hand weeded as needed. Stand pipe irrigation was used at Becker to maintain soil moisture for optimum crop growth.

The experimental design at each location was a randomized complete block with a split-split-plot restriction on randomization and three replications. Data were analyzed by analysis of variance and multiple regression procedures. Analysis was done by site, because of the large environmental differences between Becker and Rosemount. Full-model vs. reduced-model *F*-tests were used to determine if regression lines were different (Weisberg, 1985).

1992 Experiments

Soil fertility at Becker was adjusted according to soil test results by broadcasting 31 kg ha^{-1} N, 39 kg ha^{-1} P, and 192 kg ha^{-1} K during the first week of April. At planting, 14 kg ha^{-1} N, 18 kg ha^{-1} P, and 54 kg ha^{-1} K were banded 10 cm to the side of the corn row. The low level of applied N at Becker enabled us to evaluate the performance of annual medics in an environment with moderate N availability. At Rosemount, 140 kg ha^{-1} N was applied as anhydrous NH_3 in the spring before corn planting. Pioneer 3751 hybrid field corn was planted 13 May at Becker at 75 800 seeds ha^{-1}; DeKalb 421 hybrid field corn was planted 12 May at Rosemount at 64 200 seeds ha^{-1}. *Medicago scutellata* cultivars seeded were Sava and Kelson. These cultivars were selected because, although they are both relatively large seeded and have good seedling vigor, they differ for several important traits. When planted in the spring in the Upper Midwest, Sava has a determinate growth habit, senesces after 12 to 13 wk of growth, and attains a maximum height of 45 cm. Kelson has an indeterminate growth habit, senesces after 15 or more weeks of growth, and attains a maximum height of 55 cm.

The most common weed species at Becker were common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult. syn. *S. lutescens* (Weigel) F.T. Hubb.). Velvetleaf (*Abutilon theophrasti* Medik.) was the dominant weed species at Rosemount, although common lambsquarters, redroot pigweed, yellow foxtail, and giant foxtail (*S. faberii* Herrm.) were also present.

The main plots were 30.5 m long and 16 corn rows wide. Main plot treatments were weedy or weed-free. Subplots were with or without corn and were 15.25 m long and 16 corn rows wide. Sub-subplots were 7.6 m long and 4 corn rows wide. Sub-subplot treatment combinations were a 2 × 4 factorial of Sava or Kelson annual medic seeded at 0, 85, 260, or 775 seeds m^{-2}.

Dry weight 14 wk after corn emergence was taken from a 0.7-m^2 area for corn, a 0.6-m^2 area for medic, and a 1.0-m^2 area for weeds. Samples were harvested from a representative area of the plot surrounding and including the two center rows of corn. Corn ears were hand harvested from 4.6 m of the center two corn rows of each sub-subplot during the second week of October, and fresh weight was recorded. A subsample of 5 ears from each sub-subplot was weighed, dried for 4 d at 60°C, weighed, shelled, and reweighed. Corn grain yield was calculated based on 15.5% (w/w) moisture concentration. Corn stover was harvested from the same plot area as the grain and fresh weights were recorded in the field. A subsample of three to five plants was dried at 60°C for 4 d and used to calculate sub-subplot stover moisture at harvest and stover dry weight.

The land equivalent ratio (LER) for corn and medic intercrops was calculated to determine the degree of resource competition between the species. The LER for a mixture is defined as the land area required to produce a given yield when the species are grown in monoculture, divided by the land area required to obtain an equivalent yield when the species are intercropped (Vandermeer, 1989). An LER greater than 1 can be obtained if the species have different patterns of resource consumption. LERs for the corn and medic intercrop (weed-free) were calculated using the equation

$$\mathrm{LER} = (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb}) \quad [1]$$

where Y_{aa} and Y_{bb} are monocrop biomass of the component crops a (corn) and b (medic) 14 wk postemergence, and Y_{ab} is the intercrop biomass of crop a and Y_{ba} is the intercrop biomass of crop b. The two quantities in parenthesis in the LER equation are the relative yields for corn and medics, respectively. Corn mean monocrop biomass was calculated for each replicate at each location and used as the estimate for monocrop yield (Vandermeer, 1989). Medic biomass from the highest-yielding seeding rate of medics grown in monoculture was used to estimate monocrop medic biomass. Means were obtained for each cultivar and location combination.

Responses of weed dry weight 14 wk after corn emergence and corn grain yield (averaged across annual medic cultivars) to annual medic seeding rate were estimated using the hyperbolic model of Cousens (1991):

$$Y = Y_{\mathrm{mf}}\left(1 - \frac{Id}{1 + Id/C}\right) \quad [2]$$

where Y is actual weed weight or corn grain yield, d is annual medic seeding rate, and Y_{mf}, I, and C are estimated parameters denoting, respectively, weed weight or corn grain yield when grown without annual medics (mf, medic-free), yield loss (in weed weight or corn grain) per unit annual medic seeding density as d approaches 0, and maximum yield loss as d approaches infinity. This equation was originally developed to model the effects of weed interference on crop yield, but it can also be used to analyze data from competition experiments such as this, in which the dependent variables (weed weight and grain yield) respond to the independent variable (medic seeding densities) in a nonlinear way. It is particularly useful because it utilizes biologically meaningful parameters to estimate the response of the dependent variables, and because the parameter estimates generated by the model can be compared with estimates reported in the literature for other smother plants.

1993 Experiments

Soil fertility at Becker was adjusted according to soil test results with broadcast applications of 64 kg ha^{-1} P and 208 kg ha^{-1} K in early April. Commercial fertilizer was not applied at Rosemount before seeding. Hybrid field corn (Pioneer 3751) was planted 5 May at Becker at 75 800 seeds ha^{-1}, and at Rosemount 14 May at 64 200 seeds ha^{-1}.

Medics were *M. scutellata* cv. Sava and Kelson, and *M. polymorpha* L. cv. Santiago. Santiago has medium-sized seed, moderate seedling vigor, an indeterminate growth habit, and a maximum height of 30 to 35 cm; it begins to senesce after 12 to 13 wk of growth. George black medic (*M. lupulina* L.) was also seeded at Rosemount. George is a small-seeded, short-lived perennial with moderate to poor seedling vigor and a maximum height of approximately 45 cm. The 1992 data indicate that Kelson and Sava were both very competitive with corn. Santiago and George were included in the 1993 experiments because they were hypothesized to be less competitive than Kelson and Sava. Based on the results from the 1992 experiments, the seeding rate for all medic cultivars was set at 260 seeds m^{-2}. Use of a single medic seeding rate enabled us to investigate the effects of N fertilizer rates on the interactions between corn, medics, and weeds, and to evaluate additional medic cultivars.

Predominant weeds at Becker were wild buckwheat (*Polygonum convolvulus* L.), common ragweed, common lambsquarter, yellow foxtail, green foxtail (*Setaria viridis* (L.) Beauv.), smooth crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.), and redroot pigweed. At Rosemount, the most abundant weeds were common lambsquarters, redroot pigweed, ladysthumb (*Polygonum persicaria* L.), velvetleaf, and yellow foxtail.

Main plots were 22.9 m long, and were 16 or 20 corn rows wide (at Becker and Rosemount, respectively). Main plot treatments were weedy or weed-free. Subplot dimensions were 7.6 m long, by 16 or 20 corn rows wide (at Becker and Rosemount, respectively). Subplot treatments at Becker were applications of 0, 84 (medium), and 168 (high) kg ha^{-1} N broadcast in split applications as NH_4NO_3. Thirty-four kg ha^{-1} N was applied to medium- and high-N subplots on 4 May; 34 kg ha^{-1} and 100 kg ha^{-1} were applied to medium- and high-N subplots, respectively on 26 May; and 16 and 34 kg ha^{-1} N was applied to medium- and high-N subplots, respectively on 31 June. At Rosemount, subplot treatments were 0, 56, and 168 kg ha^{-1} N broadcast after corn planting on 14 May as NH_4NO_3. Sub-subplots at both sites were 7.6 m long and 4 corn rows wide. Sub-subplot treatments at Becker were no medic, Kelson, Sava, or Santiago. Rosemount sub-subplot treatments were no medic, Kelson, Sava, Santiago, or George.

Dry weight 14 wk after corn emergence was obtained from a 0.5-m^2 area of each sub-subplot for corn, and from a 0.3-m^2 area of each sub-subplot for medic and weeds. Corn ears and stover were hand harvested from 4.6 m of the center two corn rows of each sub-subplot at physiological maturity on 23 September at Becker, and on 4 October at Rosemount. Fresh weight of corn ears and stover was recorded in the field and subsamples were taken from each sub-subplot and dried for 4 d at 60°C. These results were used to determine ear moisture at harvest, corn grain yield at 15.5% (w/w) moisture, and stover dry weight as described for the 1992 experiments.

RESULTS AND DISCUSSION

1992 Experiments

Land Equivalent Ratio

Relative yields of weed-free corn and medic 14 wk after corn emergence were much more sensitive to changes in medic seeding rate at Becker than at Rosemount. The large changes in relative yields at Becker (Fig. 1a) were probably caused by low soil N availability, due to sandy soil and the relatively low rate of N fertilizer applied. The Rosemount site (Fig. 1b) was representative of the high-nutrient-status soils on which corn is often grown in the Midwest. High soil fertility at this site favored corn growth, and changes in medic seeding rate affected corn and medic relative yields much less than at Becker. At both locations, increases in medic biomass at higher medic seeding rates were offset by decreases in corn biomass. As a result, LERs were not significantly ($P < 0.05$) greater than 1 at Becker or Rosemount at any medic seeding rate.

An ideal smother plant would not compete with the main crop for resources, and the resulting main crop–smother plant intercrop should be characterized by LERs consistently greater than 1. The fact that LERs were not greater than 1 in the corn and medic intercropping system indicates that corn and medics were compet-

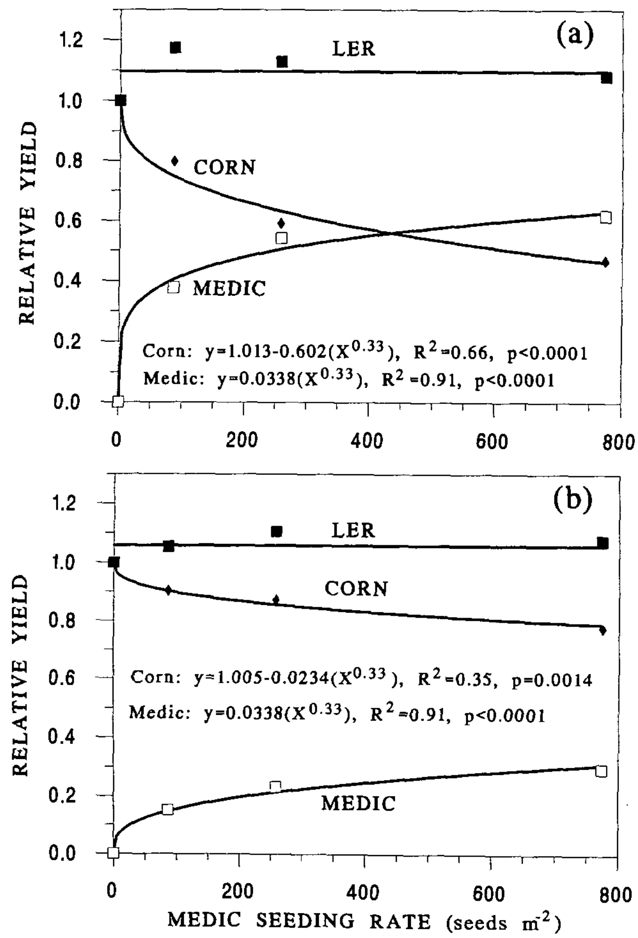

Fig. 1. Land equivalent ratio and relative yields of corn and medic from weed-free plots at (a) Becker and (b) Rosemount in 1992 based on dry weight 14 wk after corn emergence, as affected by medic seeding rate. Symbols indicate means (n = 6) averaged over Sava and Kelson annual medic cultivars. Regression equations are based on individual observations.

ing for resources, or that some other interference mechanism was involved.

Weed Control

Weed dry weight 14 wk after corn emergence was strongly influenced by corn and annual medic interference (Fig. 2). Corn interference reduced weed dry weight at 14 wk by more than 50% compared with weeds grown without corn or medics at Becker and Rosemount (weedy checks are medic plots at the 0 seeds m^{-2} medic seeding rate in Fig. 2). There were no differences in weed suppression between Sava and Kelson annual medic cultivars at either location, so results were averaged for the two cultivars. At both locations, Sava senesced during the second week of August and Kelson senesced during the last week of August. Annual medics alone seeded at the intermediate rate (258 seeds m^{-2}) reduced weed dry weight 80% at Becker, but only 20% at Rosemount, compared with dry weight of weeds grown without corn or medics. Much of the difference between locations was due to weed species. The majority of the weeds at Becker were small-seeded annual broadleaf species, which seldom emerged above the annual medic canopy. Velvetleaf was the dominant weed spe-

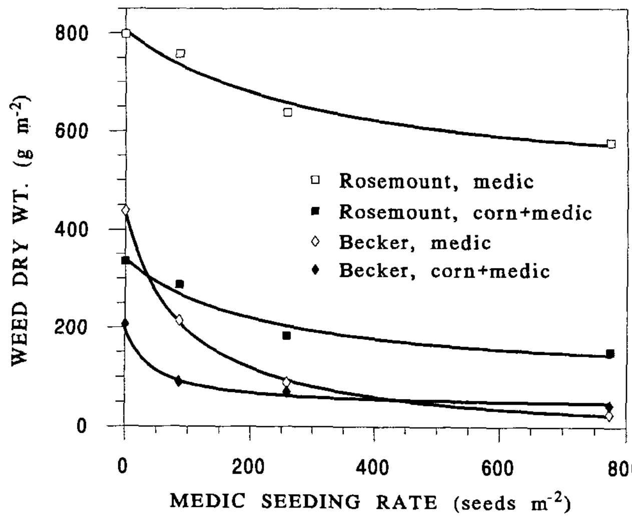

Fig. 2. Weed dry weight 14 wk after corn emergence at Becker and Rosemount in 1992 as influenced by corn and medic interference, and fitted lines from Table 1. Symbols indicate means (n = 6) averaged over Sava and Kelson annual medic cultivars.

cies at Rosemount, however, and many seedlings of this relatively large-seeded species grew up through the annual medic canopy. Soil N availability may also have been a factor in the different levels of weed dry weight suppression by annual medics at each site, as one would expect the legume smother crop to be more competitive with nonlegume weeds on the sandy soil at Becker with a low rate of applied N than on the loam soil at Rosemount that received a higher rate of applied N.

Differences in weed species and soil nutrients between locations may also have affected the relative competitive ability of corn and annual medics with weeds. At Becker, annual medics grown without corn and seeded at 258 and 774 seeds m^{-2} suppressed weed growth more effectively than corn grown without medics. At Rosemount, however, corn grown without medics reduced weed biomass more than medics grown without corn at all seeding rates.

The response of weed dry weight to medic seeding rate when medics were seeded with or without corn at Becker differed in y-intercept, but not in slope, as suggested by the parameter estimates in Table 1 and as determined by full- vs. reduced-model F-tests. This was also the case at Rosemount; however, the response of weed dry weight to medic seeding rate, averaged for corn presence or absence was different in both y-intercept and slope between locations (data not shown). This difference in slope is indicative of the ability of annual medics to suppress the small-seeded weeds present at Becker, but not the large-seeded velvetleaf at Rosemount. Based on the fitted lines (Table 1), annual medic smother plants seeded with corn at a rate just high enough to consistently suppress weeds (260 seeds m^{-2}) reduced weed biomass at Becker by 69% and at Rosemount by 41% compared with corn with no medic smother crop. Enache and Ilnicki (1990) reported similar levels of weed control when they evaluated subterranean clover as a living mulch in corn. Estimates for the I parameter (reduction in weed dry weight per unit annual medic seeding density as density approaches 0)

Table 1. Observed medic-free weed dry weight and corn grain yield in 1992, and the parameter estimates used in the nonlinear equations to generate the fitted lines for weed dry weight and corn grain yield (Fig. 2 and 3).

Variable, location, and treatment	Medic-free yield†	Parameter estimates‡		
		Y_{mf}	I	C
Weed weight at 14 wk, g m^{-2}				
Becker, medic	439	439 (37)§	0.0119 (0.0047)	1.055 (0.123)
Becker, corn + medic	207	199 (20)	0.0186 (0.0128)	0.800 (0.109)
Rosemount, medic	798	806 (80)	0.0013 (0.0021)	0.411 (0.330)
Rosemount, corn + medic	335	341 (56)	0.0034 (0.0043)	0.740 (0.393)
Corn grain yield, Mg ha^{-1}				
Becker, weed-free	6.309	6.302 (0.410)	0.0047 (0.0066)	0.2589 (0.0923)
Becker, weedy	4.146¶	—	—	—
Rosemount, weed-free	10.941	11.095 (0.393)	0.0011 (0.0008)	0.3273 (0.1132)
Rosemount, weedy	8.372#	—	—	—

† Averaged across Sava and Kelson annual medic cultivars.
‡ Y_{mf} is the medic-free yield of weeds or corn grain, I is the yield loss per unit of annual medic seeding density as density approaches 0, and C is the yield loss as medic seeding rate d approaches infinity, based on the model by Cousens (1991): $Y = Y_{mf}\{1 - [Id/(1 + Id/C)]\}$.
§ Values in parenthesis are standard errors of the parameter estimates.
¶ Mean corn grain yield over all medic seeding rates was 4.233 Mg ha^{-1}.
# Mean corn grain yield over all medic seeding rates was 8.273 Mg ha^{-1}.

from Table 1 are similar to those reported by De Haan et al. (1994) for a manipulated yellow mustard (*Brassica hirta* Moench) smother plant.

Corn Grain Yield

Corn grain yield in weed-free plots at Becker and Rosemount declined with increasing annual medic seeding rate while yields in weedy plots were relatively low, but remained constant as annual medic seeding rate increased (Fig. 3). The response of corn grain yield to annual medic presence was not different at Becker or Rosemount, except for intercept, as suggested by the parameter estimates (Table 1) and as determined by full- vs. reduced-model F-tests (analyses not shown). Based on the fitted lines, weed presence in plots without medics reduced corn grain yield 33% at Becker and 25% at Rosemount compared with monoculture corn yields. Although annual medic smother plants reduced weed biomass in the weedy treatments (Fig. 2) the decrease in weed biomass did not result in an increase in corn grain yield at the end of the growing season. This indicates that the annual medic smother plants and the weeds they displaced at Becker and Rosemount had similar competitive effects on corn. Even seeded at the highest density, however, medic smother plants did not reduce corn yield more than weeds, suggesting that, under conditions of very heavy weed pressure, the annual medic smother crop could be less competitive with corn than weeds. The fitted lines indicate that an annual medic seeding rate of 260 seeds m^{-2} (high enough to effectively reduce weed dry weight) reduced corn grain yield in weed-free plots by 21% at Becker and 15% at Rosemount compared with monoculture corn yields. Estimates of the I parameter for medics (Table 1) are higher than those reported for a manipulated yellow mustard smother plant (De Haan et al., 1994), indicating that each medic plant reduced corn yield more than each yellow mustard plant.

1993 Experiments

Corn and Medic Dry Weight

Corn dry weight from weed-free plots sampled 14 wk after emergence at Becker was reduced by medic presence at all levels of N fertilization (Fig. 4a). Corn dry weight did not differ with annual medic cultivar, and the regression line fit to data from all three cultivars gave the best prediction of corn dry weight response to annual medic presence for a range of N fertilizer rates. The medics did not differ in their effect on corn dry weight, although Sava senesced during the second week of August, while Kelson and Santiago did not senesce until the last week of August. The response of corn dry weight to N fertilizer application in plots without medics was linear, while the response in plots that contained an annual medic smother crop was curvilinear. The curvilinear response in plots with annual medics suggests that annual medics were effective competitors for N and that a N fertilization rate high enough to meet the demands of both medics and corn was necessary to diminish the competitive effects of medics on corn. These data indicate that at some high level of N fertilization it may be possible to overcome the corn dry weight reduction caused by annual medics (although from an environmental and economic perspective this may not be feasible). In this study, N was broadcast on the soil surface, making it equally available to corn, medics, and

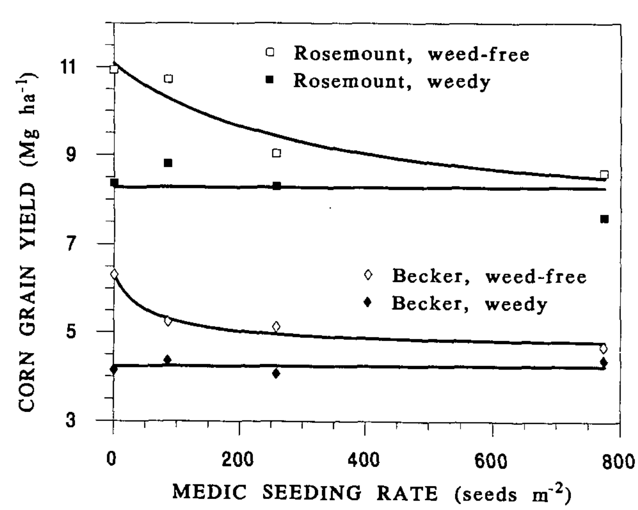

Fig. 3. Corn grain yield at Becker and Rosemount in 1992 as influenced by weed and medic interference, and fitted lines from Table 1. Symbols indicate means (n = 6) averaged over Sava and Kelson annual medic cultivars.

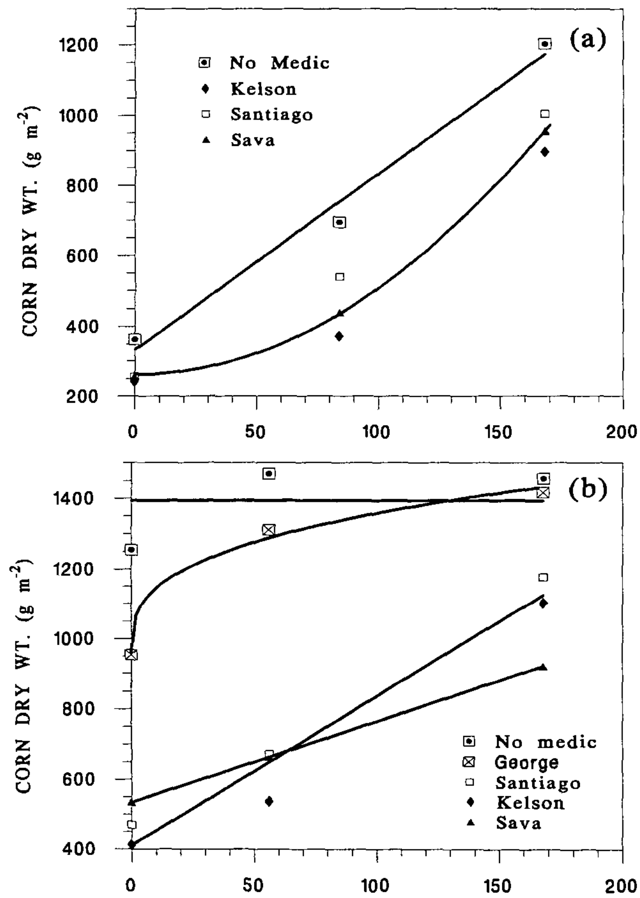

Fig. 4. Corn dry weight 14 wk after emergence in weed-free plots at (a) Becker and (b) Rosemount in 1993 as influenced by medic presence and N fertilizer application. Symbols indicate means (n = 3). Regressions (on individual observations): (a) no medic, y = 323 + 5.00 (X), R^2 = 0.89, P = 0.0001; Kelson, Santiago, and Sava combined, y = 261 + 0.0246 (X^2), R^2 = 0.83, P < 0.0001; (b) no medic, mean = 1393; George, y = 961 + 85.51 ($X^{1/3}$), R^2 = 0.88, P = 0.0001; Santiago and Kelson, y = 412 + 4.25 (X), R^2 = 0.75, P < 0.0001; Sava, y = 536 + 2.299 (X), R^2 = 0.86, P = 0.0002.

weeds. Precision application of N to a location in the soil profile favoring corn uptake rather than weed or medic uptake could reduce the N fertilizer requirement compared with broadcast applications.

In weed-free plots at Rosemount, the response of corn dry weight to N rate when grown with Santiago, Kelson, and Sava smother crops was linear (Fig. 4b), but corn dry weight at even the highest N rate was reduced by annual medic interference, compared with corn grown without annual medics. Date of annual medic senescence was not closely associated with corn dry weight response, as Sava senesced during the second week of August, while Kelson, Santiago, and George senesced at the end of the month. Increasing the rate of N fertilization in plots without medics did not affect corn dry weight, indicating that residual N was sufficient for monoculture corn growth. George annual medic reduced corn dry weight at the zero N level, but did not reduce corn dry weight compared with corn grown without medics when 56 or 168 kg ha^{-1} N were applied. These results indicate that George had a lower N requirement than Santiago, Kelson, or Sava, or that it did not compete successfully with corn for available soil N.

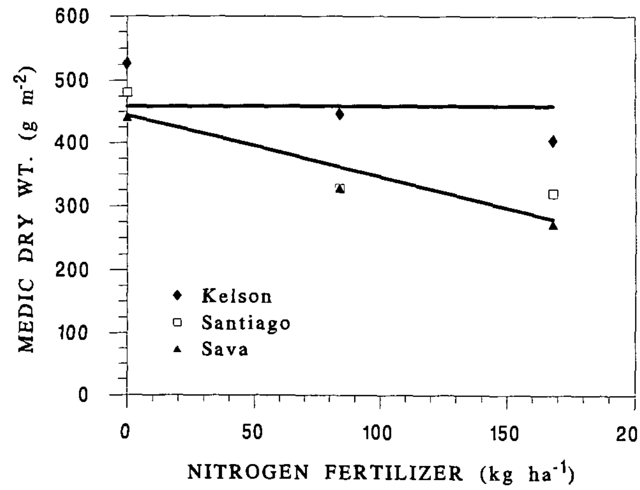

Fig. 5. Medic dry weight 14 wk after corn emergence at Becker in 1993 as influenced by N fertilizer application (averaged for weed treatments). Symbols indicate means (n = 6). Regressions (on individual observations): Kelson, mean = 459; Santiago and Sava, y = 445 − 0.99 (X), R^2 = 0.30, P = 0.0004.

Medic dry weight at 14 wk responded much differently than corn dry weight to increasing levels of N fertilization. Presence or absence of weeds did not affect medic dry weight significantly (P < 0.05), and there was no interaction between medic variety and weed presence, so the data were averaged for weed treatments. Dry weight of Kelson remained stable with increasing N rates, while the dry weight of Santiago and Sava decreased (Fig. 5). Kelson dry weight was greater than the dry weight of Santiago or Sava at all N fertilizer rates. High rates of N fertilization favored corn and weed growth and removed the competitive advantage the leguminous medics had at low soil N levels.

The response of annual medic dry weight at 14 wk to N rate at Rosemount was similar to that observed at Becker, except for the influence of weed treatments. The response was different in weed-free (Fig. 6a) than in weedy (Fig. 6b) plots for each annual medic species, but the trend was toward stable or lower annual medic dry weight in plots that received higher rates of applied N. Sava and Kelson produced more dry weight than George and Santiago at all N rates in weedy plots, but in weed-free plots with 168 kg ha^{-1} of applied N the dry weight yields of Santiago were equivalent to those of Sava and Kelson. Sava and Kelson dry weights with 0 kg ha^{-1} of applied N were much higher in weed-free plots than in weedy plots, indicating that weeds were competitive with these annual medics even at low rates of applied N, presumably due to high residual soil N levels that allowed for vigorous growth of non-N_2–fixing species. George produced less dry weight than the other medic species in weed-free plots, which may explain why it did not reduce corn dry weight at 14 wk as much as the other medic cultivars.

Weed Control

Weed dry weight at 14 wk at Becker was reduced 76% by an annual medic smother crop averaged over all rates of applied N and all annual medic cultivars (data not shown). Annual medic cultivars were similar

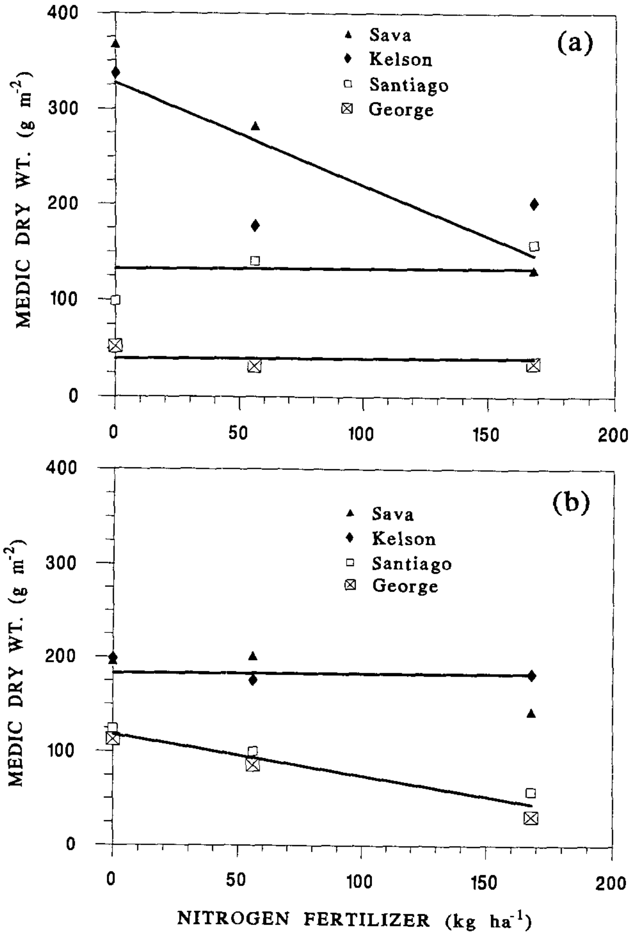

Fig. 6. Medic dry weight 14 wk after corn emergence at Rosemount in 1993 as influenced by N fertilizer application in (a) weed-free and (b) weedy plots. Symbols indicate means (n = 3). Regressions (on individual observations): (a) Sava and Kelson, $y = 327 - 1.076$ (X), $R^2 = 0.53$, $P = 0.0005$; Santiago, mean = 132; George, mean = 40; (b) Sava and Kelson, mean = 183; Santiago and George, $y = 118 - 0.436$ (X), $R^2 = 0.40$, $P = 0.0029$.

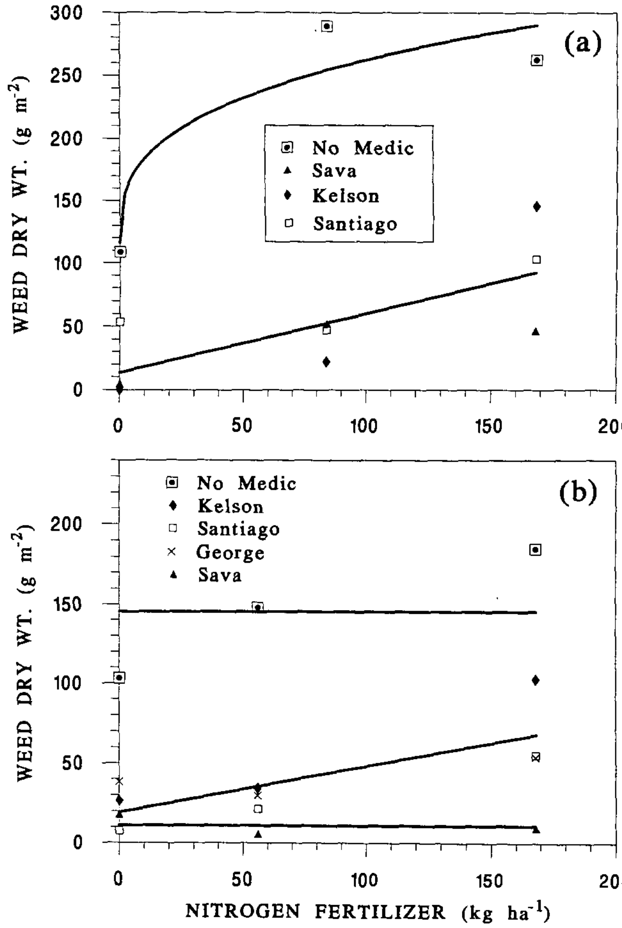

Fig. 7. Weed dry weight 14 wk after corn emergence at (a) Becker and (b) Rosemount in 1993 as influenced by N fertilization and annual medic interference. Symbols indicate means (n = 3). Regressions (on individual observations): (a) no medic, $y = 116 + 31.55$ ($X^{1/3}$), $R^2 = 0.30$, $P = 0.07$; Sava, Kelson, and Santiago, $y = 13.4 + 0.469$ (X), $R^2 = 0.35$, $P = 0.0007$; (b) no medic, mean = 145.4; Kelson, Santiago, and George, $y = 19.4 + 0.291$ (X), $R^2 = 0.23$, $P = 0.006$; Sava, mean = 11.2.

($P < 0.05$) in their ability to suppress weed dry weight. Weed dry weight increased with increased N in treatments with corn alone and in treatments with corn plus an annual medic smother crop (Fig. 7a).

At Rosemount, weed dry weight at 14 wk in corn plots without an annual medic smother crop was approximately 50% lower than at Becker (Fig. 7b). Weed dry weight in medic-free corn plots did not increase significantly ($P < 0.05$) with higher levels of applied N. Weed dry weight in corn intercropped with Kelson, Santiago, and George annual medics, however, did increase with increasing levels of applied N. The response of the three cultivars was not different, as determined by reduced vs. full model F-tests. Based on the difference between mean weed dry weight (averaged for all N rates in corn without medics) and the predicted average weed dry weight production for the three annual medics, medic smother plants reduced weed dry weight by 87% at the 0 kg ha^{-1} N rate and by 53% at the 168 kg ha^{-1} N rate. In contrast, Sava reduced weed dry weight by 92% at all levels of N fertilization. At Becker, Sava was also the most effective at reducing weed dry weight at high levels of applied N. Sava was probably the most weed competitive of the annual medic cultivars evaluated. George, however, even though it produced less biomass than other medic cultivars and was less competitive with corn, was as effective in reducing weed biomass as were Kelson and Santiago.

Corn Grain Yield

Corn grain yield at Becker in weed-free plots was linearly related to the rate of applied N in plots without annual medic smother plants, but the response was curvilinear in plots with annual medics (Fig. 8a). The corn grain yield response to applied N was similar to the response of corn dry weight at 14 wk, except that the curvilinear response of corn grain yield in plots with annual medics shifted up to overlap the no-medic yields. Corn intercropped with annual medics was apparently able to grow rapidly late in the season and compensate for dry weight reductions earlier in the yr. The compensatory corn growth may have been facilitated by N transfer from the senescing annual medics to corn. Full- vs. reduced-model F-tests indicated that separate regression lines were not warranted for annual medic cultivars,

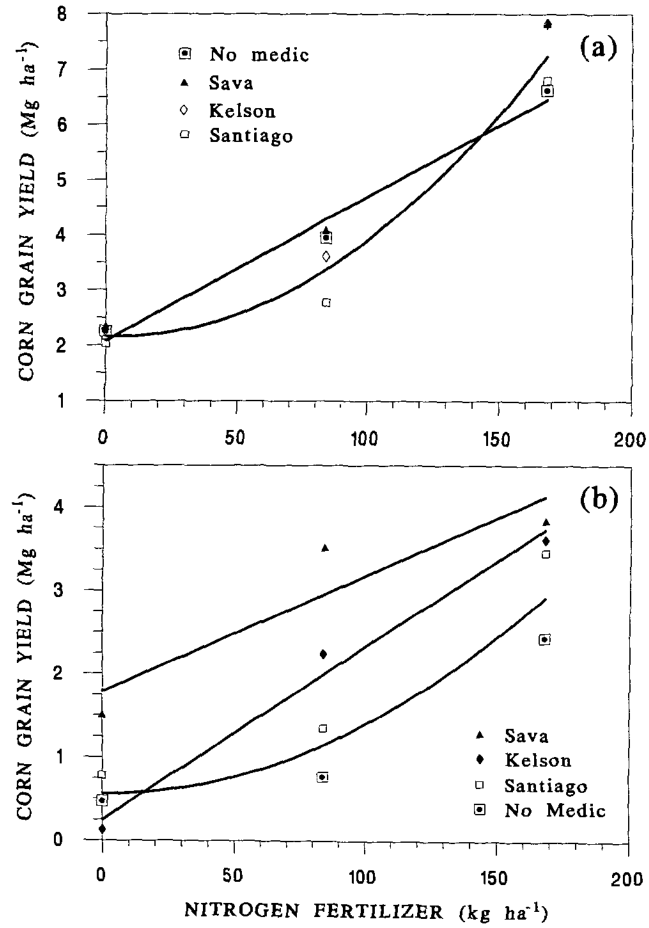

Fig. 8. Corn grain yield from (a) weed-free and (b) weedy plots at Becker in 1993 as influenced by N fertilization and annual medic interference. Symbols indicate means (n = 3). Regressions (on individual observations): (a) no medic, $y = 2091 + 26.03\ (X)$, $R^2 = 0.88$, $P = 0.0001$; Kelson, Santiago, and Sava, $y = 2168 + 0.1884\ (X^2)$, $R^2 = 0.85$, $P < 0.0001$; (b) Sava, $y = 1786 + 13.98\ (X)$, $R^2 = 0.53$, $P = 0.156$; Kelson, $y = 252 + 20.78\ (X)$, $R^2 = 0.90$, $P = 0.0001$; no medic and Santiago, $y = 561 + 0.084\ (X^2)$, $R^2 = 0.74$, $P < 0.0001$.

but analysis of variance indicated that at the 84 kg ha^{-1} N rate yield of corn grown with Santiago was lower than corn yield in the other treatments. At the 168 kg ha^{-1} N rate, corn yields from monoculture corn and the Santiago intercrop were lower than the yield of corn intercropped with Kelson or Sava.

In weedy plots at Becker, corn grain yield averaged for N rate and annual medic treatments was 2.3 Mg ha^{-1} (54%) lower than yield in weed-free plots (Fig. 8b), because of the intense weed pressure at this location. Yields of corn grown with Sava were greater than yields of corn grown in monoculture at all rates of N fertilization. Sava generally was more effective in suppressing weed growth than the other annual medics, and this may have been partially responsible for the relatively high corn grain yields obtained when it was used as a smother crop. Sava also senesced earlier than Kelson or Santiago, and N release from Sava biomass may have occurred earlier in the growing season than release from the other medic cultivars. Early release may have been important in allowing corn to take up the N before it was too mature to benefit from N inputs. Kelson also increased corn grain yields over the no medic treatment,

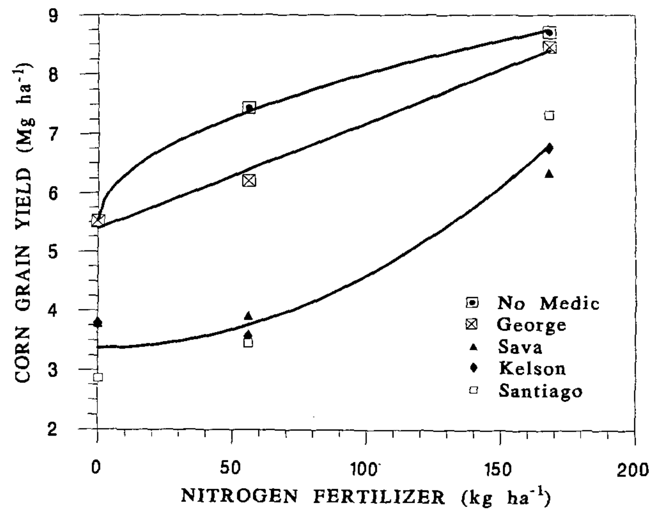

Fig. 9. Corn grain yield at Rosemount in 1993 as influenced by N fertilization and annual medic interference (averaged over weed treatments). Symbols indicate means (n = 6). Regressions (on individual observations): no medic, $y = 5527 + 248.3\ (X^{1/2})$, $R^2 = 0.75$, $P < 0.0001$; George, $y = 5398 + 17.87\ (X)$, $R^2 = 0.71$, $P < 0.0001$; Sava, Kelson, and Santiago, $y = 3380 + 0.121\ (X^2)$, $R^2 = 0.76$, $P < 0.0001$.

but only at the medium and high levels of applied N. Corn grain yield in plots with Santiago or no medic smother crop had a curvilinear response to N fertilization. Weeds were competing with corn for N and immobilized a large portion of the applied N at the 84 kg ha^{-1} N rate, thereby reducing corn grain yield. These data indicate that, at high levels of weed infestation, the annual medic cultivars evaluated can reduce corn grain yield loss due to weed competition.

At Rosemount, analysis of variance indicated that weed presence did not reduce corn grain yield so data were averaged for weed treatments. The response of corn grain yield to Sava, Kelson, and Santiago was not different over N fertilization rates, as determined by a full- vs. reduced-model F-test. Based on the predicted averages, Sava, Kelson, and Santiago reduced corn grain yield, compared with corn grown in monoculture, by 39, 49, and 22% respectively when N was applied at 0, 56, and 168 kg ha^{-1} (Fig. 9). Nitrogen fertilization of 168 kg ha^{-1} reduced the competitive effects of Sava, Kelson, and Santiago annual medic smother plants on corn grain yield, but did not eliminate them. Corn grown with George annual medic yielded better than corn grown with Sava, Kelson, or Santiago at all N fertilizer rates. Yields of corn grown with George were lower than yields from corn grown without medics at the 56 kg ha^{-1} N rate, but equivalent at the other N rates.

CONCLUSIONS

Annual medic smother plants interfered with corn growth and competed with corn for resources. When Kelson, Sava, or Santiago annual medics were seeded with corn as smother plants at a rate high enough to effectively suppress weed growth they reduced corn grain yield in most environments by approximately 20% compared with monoculture corn yields, even at high levels of applied N. Kelson, Sava, and Santiago were selected for performance as forage legumes in Australia.

They grow too large and tall and do not senesce early enough in the growing season to be ideal smother plant species for the U.S. Upper Midwest.

The annual medic smother plants evaluated were most effective in suppressing weeds at low levels of applied N, indicating that a legume smother plant grown with a N_2–fixing main crop species might provide effective weed suppression. Precision fertilizer placement may permit a similar system to work with nonlegume main crops.

Results from these experiments indicate that the response of corn and weeds to annual medic smother crops varies considerably from one location to another. Thus, it may be difficult to develop a smother plant that performs well under a wide range of soil types, fertility levels, and weed species.

Development of successful annual medic smother plants will require additional research to identify annual medic genotypes that are less competitive with corn than the Australian forage cultivars, but provide more early-season ground cover than George. Individual plants of George were not as vigorous as those of the other medic cultivars early in the season, and the upright growth habit of the cultivar produced relatively open stands at the seeding rates investigated. Competition between corn and annual medic smother plants could be reduced by selecting annual medic genotypes characterized by small individual plant size, prostrate growth habit, and a short life cycle length.

Research investigating the influence of soil type, precipitation, weed species, and soil nutrient status on medic smother plant performance will be necessary to identify the environments in which annual medic smother plants can be successfully integrated into cropping systems.

REFERENCES

Ateh, C.M., and J.D. Doll. 1996. Spring-planted winter rye (*Secale cereale*) as a living mulch to control weeds in soybean (*Glycine max*). Weed Technol. 10:347–353.

Bruce, R.R., G.W. Langdale, L.T. West, and W.P. Miller. 1992. Soil surface modification by biomass inputs affecting rainfall infiltration. Soil Sci. Soc. Am. J. 56:1614–1620.

Bunting, E.S., and J.W. Ludwig. 1964. Plant competition and weed control in maize. Proc. Br. Weed Control Conf. 7(1):385–388.

Corak, S.J., W.W. Frye, and M.S. Smith. 1991. Legume mulch and nitrogen fertilizer effects on soil water and corn production. Soil Sci. Soc. Am. J. 55:1395–1400.

Cousens, R. 1991. Aspects of the design and interpretation of competition (interference) experiments. Weed Technol. 5:664–673.

Cripps, R.W., and H.K. Bates. 1993. Effect of cover crops on soil erosion in nursery aisles. J. Environ. Hortic. 11(1):5–8.

Curran, W.S., L.D. Hoffman, and E.L. Werner. 1994. The influence of a hairy vetch (*Vicia villosa*) cover crop on weed control and corn (*Zea mays*) growth and yield. Weed Technol. 8:777–784.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86:126–135.

De Haan, R.L., D.L. Wyse, N.J. Ehlke, B.D. Maxwell, and D.H. Putnam. 1994. Simulation of spring-seeded smother plants for weed control in corn (*Zea mays*). Weed Sci. 42:35–43.

Eadie, A.G., C.J. Swanton, J.E. Shaw, and G.W. Anderson. 1992. Integration of cereal cover crops in ridge-tillage corn (*Zea mays*) production. Weed Technol. 6:553–560.

Eberlein, C.V., C.C. Sheaffer, and V.F. Oliveira. 1992. Corn growth and yield in an alfalfa living mulch system. J. Prod. Agric. 5:332–339.

Echtenkamp, G.W., and R.S. Moomaw. 1989. No-till corn production in a living mulch system. Weed Technol. 3:261–266.

Enache, A.J., and R.D. Ilnicki. 1990. Weed control by subterranean clover (*Trifolium subterraneum*) used as a living mulch. Weed Technol. 4:534–538.

Fischer, A., and L. Burrill. 1993. Managing interference in a sweet corn–white clover living mulch system. Am. J. Altern. Agric. 8:51–56.

Grubinger, V.P., and P.L. Minotti. 1990. Managing white clover living mulch for sweet corn with partial rototilling. Am. J. Altern. Agric. 5:4–12.

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

Hanson, J.C., E. Lichtenberg, A.M. Decker, and A.J. Clark. 1993. Profitability of no-tillage corn following a hairy vetch cover crop. J. Prod. Agric. 6:432–437.

Hoffman, M.L., E.E. Regnier, and J. Cardina. 1993. Weed and corn (*Zea mays*) responses to a hairy vetch (*Vicia villosa*) cover crop. Weed Technol. 7:594–599.

Johnson, G.A., M.S. Defelice, and Z.R. Helsel. 1993. Cover crop management and weed control in corn (*Zea mays*). Weed Technol. 7:425–430.

Knake, E.L., and F.W. Slife. 1965. Giant foxtail seeded at various times in corn and soybeans. Weeds 13:331–334.

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

Kumwenda, J.D.T., D.E. Radcliffe, W.L. Hargrove, and D.C. Bridges. 1993. Reseeding of crimson clover and corn grain yield in a living mulch system. Soil Sci. Soc. Am. J. 57:517–523.

Maskina, M.S., J.F. Power, J.W. Doran, and W.W. Wilhelm. 1993. Residual effects of no-till crop residues on corn yield and nitrogen uptake. Soil Sci. Soc. Am. J. 57:1555–1560.

Mohler, C.L. 1991. Effects of tillage and mulch on weed biomass and sweet corn yield. Weed Technol. 5:545–552.

Nieto, J.H., M.A. Brando, and J.T. Gonzales. 1968. Critical periods of the crop growth cycle for competition from weeds. Pest Artic. News Summ. (C) 14:159–166.

Stute, J.K., and J.L. Posner. 1993. Legume cover crop options for grain rotations in Wisconsin. Agron. J. 85:1128–1132.

Teasdale, J.R. 1993. Reduced-herbicide weed management systems for no-tillage corn (*Zea mays*) in a hairy vetch (*Vicia villosa*) cover crop. 1993. Weed Technol. 7:879–883.

Thomas, P.E.L., and J.C.S. Allison. 1975. Competition between maize and *Rottboellia exaltata* Linn. J. Agric. Sci. 84:305–312.

Tollenaar, M., M. Mihajlovic, and T.J. Vyn. 1993. Corn growth following cover crops: influence of cereal cultivar, cereal removal, and nitrogen rate. Agron J. 85:251–255.

Vandermeer, J.H. 1989. The ecology of intercropping. Cambridge Univ. Press, Cambridge.

Weisberg, S. 1985. Applied linear regression. 2nd ed. John Wiley & Sons, New York.

Welty, L.E., L.S. Prestbye, R.E. Engel, R.A. Larson, R.H. Lockerman, R.S. Spielman et al. 1988. Nitrogen contribution of annual legumes to subsequent barley production. Appl. Agric. Res. 3(2):98–104.

Wilkins, E.D., and R.R. Bellinder. 1996. Mow-kill regulation of winter cereals for spring no-till crop production. Weed Technol. 10: 247–252.

Yenish, J.P., A.D. Worsham, and A.C. York. 1996. Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technol. 10:815–821.

Zhu, Y., C.C. Sheaffer, and D.K. Barnes. 1996. Forage yield and quality of six annual *Medicago* species in the north-central USA. Agron. J. 88:955–960.

Zimdahl, R.L. 1988. The concept and application of the critical weed-free period. p. 145–155. *In* M.A. Altieri and M. Liebman (ed.) Weed management in agroecosystems: Ecological approaches. CRC Press, Boca Raton, FL.