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The Impact of Intercropping Annual 'Sava' Snail Medic on Corn Production

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ABSTRACT

Interseeding a leguminous cover crop into corn (*Zea mays* L.) may reduce corn yields. By understanding the mechanisms responsible for yield reductions, improved management strategies can be developed. The objective of this study was to determine the influence of an annual medic (*Medicago scutellata* Mill cv. Sava) interseeded into corn at planting on N and water stress in corn. Field research was conducted at three South Dakota sites. Treatments were two broadcast medic (0 and 33 kg ha^{-1}) and two N (0 or recommended) rates. Water infiltration was measured at Aurora in 1997 and 1998. Carbon-13 discrimination (Δ) in corn grain was measured at Aurora in 1998 and Beresford in 1998. Medic biomass at Aurora in 1997, Aurora in 1998, and Beresford in 1998 was 1290, 215, and 913 kg ha^{-1}, respectively. At Aurora, on 11 July 1997, medic increased water infiltration from 0.0156 to 0.035 cm s^{-1}. Similar results were measured at Aurora in 1998. Medic reduced corn growth as early as 17 July at Aurora in 1997 and 19 June at Beresford in 1998. Associated with reduced corn biomass production in the fertilized treatments were lower N concentration and fertilizer efficiency. Interseeding medic into corn did not increase Δ in corn at Beresford in 1998 or Aurora in 1998. These results suggest that the negative effects of medic on corn primarily resulted from N stress and not increased water stress. Given these results, management strategies that reduce the competition between medic and corn for N should be developed.

Any time that the soil has minimal crop residue present, wind and water erosion can be serious problems in the Great Plains region of the USA. Management practices targeted to reduce soil erosion between tillage and canopy closure are needed. Small-seeded legumes interseeded into a primary crop may fill this need because they have been reported to (i) dissipate raindrop energy, which reduces aggregate destruction and erosion (Mannering and Fenster, 1983; Foster et al., 1985); (ii) increase aggregate stability (Tisdall and Oades, 1982); (iii) increase water infiltration rates; and (iv) reduce runoff (Wilson et al., 1982; Toughton et al., 1984; McVay et al., 1989; Bruce et al., 1992). In addition, interseeded species may also recover excess nutrients that otherwise may be lost from the system (Ditsch et al., 1993).

Annual snail medic may be suited for interseeding into corn in the Great Plains because it has a short life cycle (12–14 wk), is a cool-season plant, and has a determinate growth habit (DeHann et al., 1997; Vos, 1999). Medic is also capable of fixing atmospheric N and may suppress weed growth (Buhler et al., 1998; DeHaan et al., 1997; Vos, 1999). In the north-central USA, annual medics have been evaluated for their potential use as a forage and smother crop (Moynihan et al., 1996; DeHaan et al., 1997; Buhler et al., 1998). This research has shown that medic can reduce weed and corn biomass production at seeding rates as low as 14 kg ha^{-1} seed. The planting date of the intercrop in the Great Plains is critical because if they are planted too late, then they may have a limited impact on reducing wind or water erosion and if planted too early, they may reduce primary crop yield (Jeranyama et al., 1998).

Interseeded crops can reduce primary crop yields through allelopathy and competition for nutrients, water, and light. In semiarid environments such as the Great Plains, water used by the interseeded crops may reduce plant-available water, which can reduce yields. Yield loss due to the interseeded crop can be reduced by delaying the planting date of the interseeded crops (Jeranyama et al., 1998). However, delaying the planting date also reduces the potential for the interseeded crop to reduce wind and water erosion. To resolve this dilemma, the mechanisms causing yield reductions in the primary crop must be known. Once mechanisms are known, solutions can be developed.

Interseeded crops have the potential to compete with or provide nutrients to the primary crop. The impact of the interseeded crop on N utilization by the primary crop can be evaluated by using nonisotopic as well as ^{15}N natural abundance (Clay, 1997; Zhu et al., 1998), ^{15}N enrichment, and ^{15}N depleted methods. A common feature of all isotopic methods is that different N sources have different ^{15}N/^{14}N ratios.

If the interseeded crop is a legume, then symbiotic N fixation may add N to the cropping system (Heichel and Barnes, 1984; Frye et al., 1988; Loi et al., 1993). The amount of N fixed by medic is variable and has been reported to be as high as 200 kg N ha^{-1} (Zhu et al., 1998). The amount of N transferred from leguminous to nonleguminous plants depends on the legume, cropping system, climatic conditions, and N uptake kinetics of the nonleguminous crop (Tomm et al., 1994; Walley et al., 1996). Benefits from N fixation may occur during the year that the legume is planted or in subsequent years. Hargrove (1986) reported that the average fertilizer replacements of four winter legume cover crops was 72 kg N ha^{-1}. Jeranyama et al. (1998) reported that

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Abbreviations: ET, evapotranspiration; Δ, ^{13}C discrimination; $\delta\Delta_{N\ stress}$, the change in ^{13}C discrimination for each percentage of yield lost due to N stress; $\delta\Delta_{water\ stress}$, the change in ^{13}C discrimination for each percentage of yield lost to water stress.

medic intercropped into corn had a fertilizer replacement value for the subsequent crop of 13 to 18 kg N ha^{-1}. Amado et al. (1998) reported that 61 kg N ha^{-1} inorganic N was needed for corn following fallow to equal the corn yield following common vetch (*Vicia sativa* L.) in southern Brazil. The transfer mechanism has been attributed to the mineralization of plant residues followed by plant uptake.

The impact of water stress on crops grown under field conditions is difficult to assess because water can be lost from the system by a variety of mechanisms, including evaporation, transpiration, runoff, and leaching. Techniques that measure the impact of management on water stress may combine evaporation and transpiration into a single measurement of evapotranspiration (ET). Separating ET into transpiration and evaporation may be required to assess the impact of interseeded crops on water availability to the primary crop because if the interseeded crop obtains water from the soil surface that typically is lost to evaporation and the primary crop obtains water from deeper soil depths, then the two crops may not directly compete for water.

Many of the commonly used techniques for measuring water use do not separate evaporation and transpiration. For example, in the mass balance approach, ET has been estimated using the following equation: ET = precipitation − soil water at the end of the season + soil water at the beginning of the season. This equation assumes that runoff, runon, and leaching are insignificant. Clearly, this assumption is not valid for fields with topographic relief. This assumption may not even be valid in relatively flat fields with course-textured soils. Delin et al. (2000) reported that water redistribution occurs in coarse-textured soils with relatively small slopes (<2%). In sloping land, runoff or runon can be measured, modeled, or estimated from topographic information. For example, Halvorson and Doll (1991) addressed the runoff and runon problem using topography to calculate a topographic factor. If the factor was positive, then a net gain in runon was expected and if negative, then a net loss from runoff was expected. They used the topographic factor to predict areas where runoff was expected and to move an appropriate amount of water to areas where runon was expected. This approach worked better in wet than dry years.

An alternative approach to measuring transpiration is to measure a time-integrated value that is related to water stress. The amount of ^{13}C discrimination (Δ) occurring in C_3 and C_4 plants provides an time-integrated index of stomatal closure (Farquar and Lloyd, 1993). In order to understand why Δ provides an index of water stress, background information is needed. First, Δ is influenced by plant type, stomatal conductance, photosynthesis capacity, and the plant water demand (Clay et al., 2001a, 2001b). Water stress influences Δ because the amount of $^{13}CO_2$ and $^{12}CO_2$ fixed during photosynthesis is influenced by the relative amounts $^{13}CO_2$ and $^{12}CO_2$ in the leaf. In C_4 plants, the relative amount of $^{12}CO_2$ fixed during photosynthesis increases with increasing water stress (stomatal closure). Photosynthesis-induced C isotope fractionation in C_4 (Δ_{c4}) plants is described by the equation:

$$\Delta_{c4} = a + [b_4 + \phi(b_3 - s) - a]C_i/C_a \qquad [1]$$

where

a = ^{13}C discrimination due to CO_2 diffusion in air
b_4 = ^{13}C discrimination of gaseous CO_2 through phosphoenolpyruvate (PEP) carboxylase (−5.7‰)
b_3 = ^{13}C discrimination due to ribulose bisphosphate carboxylase (RuBisCO) (30‰)
ϕ = ratio of the rate of CO_2 leakage from the bundle sheath to the rate of PEP carboxylation (leakiness)
s = fractionation during this process
C_i = internal CO_2 partial pressure
C_a = external CO_2 partial pressure (O'Leary, 1993; Farquhar and Lloyd, 1993)

When $s = 0$ and $\phi = 0.21$, Eq. [1] predicts that as C_i/C_a approaches 0 (stomata closed), Δ_{c4} approaches 4.4 and as C_i/C_a approaches 1 (stomata open), Δ_{c4} approaches 0.6. An advantage of using Δ as a water stress index is that it provides a spatially and temporally integrated value.

Clay et al. (2001a) tested if Δ could be used to evaluate water stress–induced yield reductions in corn. In this study, corn located at different landscape positions was watered and not watered. In the nonwatered areas, summit soils were dryer than footslope soils for the entire growing season. In the footslope area, watered (154 g grain $plant^{-1}$) and unwatered (164 g grain $plant^{-1}$) plants had similar yields and Δ values. However, in summit soils, yields were lower in nonwatered (87 g $plant^{-1}$) than watered plants (145 g $plant^{-1}$), and nonwatered plants (3.35‰) had higher Δ than watered plants (3.11‰). In the same study, the authors reported that Δ contained spatial structure, Δ was highest in summit soils and lowest in footslope soils, and that Δ could be used to estimate yield losses due to water stress. Data from this study were used to calculate that for every 1% decrease in relative corn yield due to water stress, Δ increased 0.0117‰.

Clay et al. (2001b) also used C isotopic discrimination to calculate yield losses due to N and water stress in wheat (*Triticum aestivum* L.). They showed that by defining the impact of N on Δ, yield losses due to water and N stress could be calculated. In this study, under non–N limiting conditions, the impact of water stress on yield was defined by the equation: yield (kg ha^{-1}) = $-11\,000 + 884\Delta$ [$r = 0.92$ (significant at the 0.01 level)].

Once the causes for yield reduction are understood, management practices designed to make best use of the available resources can be developed. The objective of this study was to determine the influence of an annual medic (variety Sava) interseeded into corn at planting on N and water stress in corn.

MATERIALS AND METHODS

In 1997 and 1998, research was conducted at sites located near Aurora, SD (44.31 N, 96.67 W), on a Brandt silty clay loam (fine-silty, mixed superactive, frigid, Calcic Hapludoll) soil. In 1998, an additional site was located near Beresford, SD (43.05 N, 96.70 W) on a Trent silty clay loam (fine-silty, mixed, mesic Pachic Haplustoll).

The experimental design for each site was a randomized complete block with four replications. Factorial treatments were two snail medic (cultivar Sava) seeding rates (0 and 33 kg ha^{-1}) and two N fertilizer rates (0 and the N recommendation based on the NO_3–N test) (Gerwing and Gelderman, 1996). The row spacing at all sites was 76 cm. Based on spring soil tests, all plots were fertilized with P and K (Gerwing and Gelderman, 1996).

At Aurora in 1997, corn was planted on 5 May at a rate of 69 000 seeds ha^{-1}, urea was broadcast-applied following planting at rates of 0 or 134 kg N ha^{-1}, and inoculated snail medic was planted with an alfalfa seeder on 9 May. To stimulate medic germination and growth and to move the urea into the soil, 1 cm of irrigation water was applied in May. To control weeds, an interrow cultivation was conducted on 2 July. At Aurora in 1998, corn was planted at a rate of 69 000 seeds ha^{-1} on 5 May, urea was broadcast following planting at rates of 0 or 146 kg N ha^{-1}, inoculated snail medic was broadcast, and urea and medic were raked into the soil. Irrigation water was not applied at Aurora in 1998. At Beresford in 1998, corn was planted at the rate of 69 000 seeds ha^{-1} on 24 April, urea was broadcast-applied following planting at rates of 0 and 143 kg ha^{-1} urea N, inoculated medic was broadcast, and urea and medic were raked into the soil on 24 April. Irrigation water was not applied at Beresford 1998.

Soil samples, a composite of eight 2-cm cores, were collected from each plot in 15-cm increments to a depth of 60 cm before fertilizing and after corn harvest. Nitrate N and NH_3–N were extracted from 10 g of air-dried soil with 100 mL of 1 *M* KCl and analyzed using the Cd reduction and phenate methods, respectively (Maynard and Kalra, 1993).

Water Infiltration

Water infiltration at Aurora was measured at one site in each plot on 11 June, 19 June, 11 July, and 19 July 1997 and on 20 August and 28 August 1998. The double-ring infiltrometer used to measure infiltration consisted of an outside ring with a diameter of 34 cm and an inside ring with a diameter of 15 cm (Lowery et al., 1996). The rings were driven 15 cm into the soil in the center of the interrow. The amount of water needed to cover the ring area to a depth of 2.5 cm was added to each ring. Twenty-four hours later, rings received an additional 2.5 cm of water, and the length of time for water to completely infiltrate into inner ring soil was measured.

Nitrogen Budget Calculations

Net N mineralization in the unfertilized plots was calculated using the N balance approach. Net N mineralization was calculated with the equation: net N mineralization = N contained in grain and stover at harvest − final inorganic soil N at harvest + initial inorganic soil N at planting. In this equation, plant N at harvest was the total amount of N contained in the aboveground biomass, and inorganic soil N at planting and harvest was the amount inorganic N contained in the 0- to 60-cm depth of soil. This method assumed that N lost through leaching and denitrification was insignificant.

Medic biomass was harvested, when maximum biomass was expected, from two 0.35-m^2 areas in each plot at Aurora 1997 on 2 July, Aurora 1998 on 27 July, and Beresford 1998 on 19 July. Corn biomass was harvested from a 1.52-m^2 area at Aurora 1997 (18 June, 2 July, and 17 July), Aurora 1998 (11 June and 27 July), and Beresford 1998 (19 June and 5 August). On 1 October, 8 October, and 23 September, corn grain and stover were harvested from 9.27-m^2 areas at Aurora 1997, Aurora 1998, and Beresford 1998, respectively. Harvested plants were dried, weighed, and analyzed for total N and $\delta^{15}N$ on an Europa 20-20 ratio mass spectrometer (Europa Sci., Westchester, UK). The $\delta^{15}N$ values were calculated with the following equation:

$$\delta^{15}N = \{[(^{15}N/^{14}N_{sample} - {}^{15}N/^{14}N_{standard})/(^{15}N/^{14}N_{standard})] \times 1000\}‰ \quad [2]$$

where $^{15}N/^{14}N_{sample}$ is the isotopic ratio of N in a sample and $^{15}N/^{14}N_{standard}$ is the isotropic ratio of the standard, air (0.0036765) (Barrie and Prosser, 1996).

To determine the impact of the N and medic treatments on N uptake by the subsequent crop, oat (*Avena sativa* L.) was planted in 1998 at Aurora 1997, 1999 at Aurora 1998, and 1999 at Beresford 1998. Oat biomass samples were harvested at the point of maximum biomass accumulation (July) in 1998 (Aurora 1997) and 1999 (Aurora 1998 and Beresford 1998) from a 0.3-m^2 area in each plot. Oat biomass was dried, weighted, ground, and analyzed for total N and $\delta^{15}N$ on an Europa 20-20 ratio mass spectrometer.

The contribution of medic toward meeting corn N requirement in the unfertilized plots was calculated using the following equation:

$$\%\ N\ from\ medic = 100[1 - (\delta^{15}N_a - \delta^{15}N_b)/(\delta^{15}N_c - \delta^{15}N_b)] \quad [3]$$

where $\delta^{15}N_a$ is the $\delta^{15}N$ of corn in the medic–zero N plots, $\delta^{15}N_b$ is the $\delta^{15}N$ of medic in the zero-N plots, and $\delta^{15}N_c$ is the $\delta^{15}N$ of corn in the no medic–zero N plots (Shearer and Kohl, 1992; Clay, 1997).

Fertilizer efficiency (%FE) was calculated using the equation:

$$\%FE = 100[(NTF - Ncontrol)/Nrate] \quad [4]$$

where NTF is the N contained in the aboveground corn biomass, Nrate is the amount of N applied, and Ncontrol is N contained in the aboveground biomass of the unfertilized plot within the block.

Carbon-13 Discrimination and Yield Losses Due to Water and Nitrogen Stress

Grain and stover samples from Aurora 1998 and Beresford 1998 were analyzed for $\delta^{13}C$ and Δ. The $\delta^{13}C$ was calculated with the following equation:

$$\delta^{13}C = [R(sample)/R(standard) - 1] \times 1000‰ \quad [5]$$

where R(sample) is the $^{13}C/^{12}C$ ratio of the sample and R(standard) is the $^{13}C/^{12}C$ ratio of PDB, a limestone from the Pee Dee formation in South Carolina (Farquhar and Lloyd, 1993; O'Leary, 1993). Typically, $\delta^{13}C$ values for air, C_3, and C_4 plants are −8, −27, and −13‰, respectively. A negative sign indicates that the sample has a lower $^{13}C/^{12}C$ ratio than PDB. The $\delta^{13}C$ values were used to calculate Δ using the following equation:

$$\Delta = (\delta^{13}C_a - \delta^{13}C_p)/(1 + \delta^{13}C_p/1000) \quad [6]$$

where $\delta^{13}C_a$ is the $\delta^{13}C$ value of air (−8‰) and $\delta^{13}C_p$ is the $\delta^{13}C$ value of the plant.

The data from Clay et al. (2001a), combined with findings from this study, and the approach described by Clay et al. (2001b) were used to calculate yield losses due to water and N stress. Clay et al. (2001b) suggested that the total yield losses due to water and N stress could be separated into two components. Yield loss due to N stress was defined as the difference between measured yield and the expected yield if N was applied in excess of the plant requirement. Yield loss due to water stress was defined as the difference between the maximum yield and the yield obtained under non–N limiting conditions. Using this approach, the equations were

$$\mathrm{TYL} = X + Y \quad [7]$$

$$\delta\Delta = X \times \delta\Delta_{\text{water stress}} + Y \times \delta\Delta_{\text{N stress}} \quad [8]$$

where

TYL = the total percentage yield loss
X = the percentage yield loss due to water stress
Y = the percentage yield loss due to N stress
$\delta\Delta$ = the change in Δ in corn due to adding medic
$\delta\Delta_{\text{water stress}}$ = the change in Δ for each percentage of yield lost to water stress (Clay et al., 2001a)
$\delta\Delta_{\text{N stress}}$ = the change in Δ for each percentage of yield lost due to N stress (derived below)

Clay et al. (2001a) showed that to produce a 30% yield loss to water stress, Δ increased 0.35‰. Using this data, $\delta\Delta_{\text{water stress}}$ was estimated to be 0.0117‰ (percentage loss in relative yield)$^{-1}$.

Analysis of variance was used to evaluate treatment differences. For main effects, a F-test at the 0.05 level was used to determine treatment differences, and for interactions, a Fisher LSD at the 0.05 level was used to determine treatment differences.

Climatic Calculations and Conditions

Daily maximum and minimum temperatures and rainfall for each day were measured at weather stations located at each site. Growing degree days (GDD) were calculated using the following equation:

$$\mathrm{GDD}\ (^\circ\mathrm{C}) = \Sigma[(\mathrm{Tmin} + \mathrm{Tmax})/2] - 10 \quad [9]$$

where Tmin is the minimum daily temperature and Tmax is the maximum daily temperature. In this equation, the minimum temperature was 10°C. The growing degree days at Aurora 1997 (1290 GDD) and Aurora 1998 (1467 GDD) were less than and similar to the long-term average of 1419 GDD, respectively. At Beresford 1998, the number of GDD (1803) was higher than the long-term average of 1616 GDD.

Rainfall plus irrigation between May and September at Aurora 1997, Aurora 1998, and Beresford 1998 was 30.4, 34.5, and 24.9 cm, respectively. At Aurora and Beresford, the rainfall plus irrigation totals were less than the long-term precipitation averages between May and September of 38.0 and 40.6 cm, respectively.

RESULTS AND DISCUSSION

Medic Production

At all sites, medic production peaked in July and had senesced by late August. At Beresford 1998, medic biomass production and the N contained within medic was increased by N addition (Table 1).

Water Infiltration

Water infiltration rates at Aurora in June 1997 were not influenced by N or medic (Table 2). However, in July, medic increased water infiltration rates by 120%. Plots without medic had smooth soil surfaces, indicating that surface sealing occurred while plots with medic were rough. At Aurora 1998, similar results were observed although measured later in the season. These results were attributed to medic protecting the surface soil from raindrop impact (Foster et al., 1985; Bruce et al., 1992; Kohl and Schumacher, 1999). Increasing water infiltration has the potential to reduce runoff and erosion and increase plant-available water.

Medic and Nitrogen Influence on Nitrogen Budgets

Soil Inorganic Nitrogen

The amount of inorganic N (NO_3^- + NH_4^+) contained in the surface 60 cm before planting corn at Aurora 1997, Aurora 1998, and Beresford 1998 was 9, 43, and 47 kg N ha^{-1}, respectively. The small amount of inorganic N at Aurora 1997 was attributed to fertilizer not being applied to the site for the previous 7 yr. Following harvest, inorganic N (NO_3^- + NH_4^+) contained in the surface 60 cm of soil at Aurora 1997, Aurora 1998, and Beresford 1998 was not influenced by fertilizer or medic and averaged 39, 52, and 34 kg N ha^{-1}, respectively.

Corn Production

Corn biomass reduction in medic-interseeded areas was detected on 17 July and 19 June at Aurora 1997

Table 1. The influence of N fertilizer application on medic biomass production and N contained in the aboveground portion of the plant at the three locations.

	Aurora 1997 2 July 1997		Aurora 1998 27 July 1998		Beresford 1998 19 July 1998	
Treatment	Medic	Total N	Medic	Total N	Medic	Total N
	kg ha^{-1}	kg N ha^{-1}	kg ha^{-1}	kg N ha^{-1}	kg ha^{-1}	kg N ha^{-1}
0N	720	22.8	266	4.9	826	26.0
+N	1570	65.7	166	5.4	1000	36.3
ANOVA (probability of a larger F-value)						
N Fertilizer	0.15	0.20	0.91	0.80	0.04	0.04
CV, %	35.0	31.2	23.2	113	16.4	18.9

Table 2. The influence of two medic treatments (+M and 0M) and two N fertilizer rates (+N and 0N) on water infiltration at Aurora 1997 and Aurora 1998.

		Aurora 1997				Aurora 1998	
		June		July		August	
Medic	Fertilizer	11	19	11	19	20	28
		cm s^{-1}					
0M	0N	0.0096	0.0095	0.0248	0.0039	0.0043	0.0038
+M	0N	0.0076	0.0174	0.0289	0.0170	0.0179	0.0115
0M	+N	0.0044	0.0059	0.0062	0.0038	0.0047	0.0031
+M	+N	0.0096	0.0300	0.0411	0.0113	0.0155	0.0156
Main effects							
0M		0.007	0.008	0.0155	0.0038	0.0045	0.0035
+M		0.007	0.0237	0.035	0.0142	0.0167	0.0136
ANOVA (probability of a larger F-value)							
Medic		0.58	0.10	0.02	0.05	0.07	0.05
N fert.		0.39	0.41	0.57	0.90	0.85	0.68
Medic × N fert.		0.58	0.71	0.75	0.84	0.84	0.85
CV, %		24.1	7.45	3.69	22.0	17.4	26.0

and Beresford 1998, respectively (Table 3). Associated with biomass reductions, in the fertilized treatments, a reduction in corn N concentration from 26.7 to 21.5 g kg^{-1} was detected on 17 July 1997 at Aurora. Medic also reduced the N concentration in the fertilized plots at Beresford 1998 on 19 June from 34.8 to 26.7 g kg^{-1}. Medic-induced reductions in corn biomass and N concentration suggest that medic reduced yields either through allelopathy or N stress. Allelopathic effects of medic on corn was discounted because Vos (1999) reported that leaf extracts from medic did not inhibit corn seed germination or seedling growth. Yield reductions due to medic were still evident at harvest (Table 3).

At Aurora 1998, medic did not influence corn production. The lack of differences at Aurora 1998 most likely resulted from low medic biomass production (Table 1). At all sites, N fertilizer increased N contained in corn grain and stover production (Table 4).

Table 3. The influence of two medic treatments (+M and 0M) and two N rates (+N and 0N) on corn biomass and grain yield.

Aurora 1997					1 October		
Treatment		18 June	2 July	17 July	Grain	Stover	Total corn
		kg ha^{-1}					
0M	0N	280	1 590	4 340	7 880	4 620	12 500
+M	0N	230	1 240	3 340	4 680	3 710	10 190
0M	+N	370	1 210	4 480	9 500	5 140	14 640
+M	+N	290	1 250	4 440	8 590	4 570	13 170
Main effects							
0M		325	1 400	4 410	8 690	4 880	13 570
+M		260	1 250	3 890	6 640	4 140	11 680
	0N	260	1 420	3 840	6 280	4 165	11 350
	+N	660	1 230	4 460	9 050	4 860	13 910
ANOVA (probability of a larger *F*-value)							
Medic		0.27	0.40	0.02	0.02	0.02	
N fert.		0.19	0.31	<0.01	<0.01	0.02	0.02
Medic × N fert.		0.82	0.282	0.03	0.57	0.55	0.55
CV, %		35.2	25.8	9.00	10.2	10.9	10.5
Aurora 1998					8 October		
Treatment		11 June	27 July		Grain	Stover	Total corn
0M	0N	59.2	6 220		7 570	5 710	13 280
+M	0N	59.9	5 340		6 350	4 320	10 670
0M	+N	66.3	7 720		8 710	5 440	14 160
+M	+N	61.3	7 180		8 860	5 330	14 160
Main effects							
	0N	59.6	5 780		6 960	5 020	11 980
	+N	63.8	7 450		8 790	5 390	14 160
ANOVA (probability of a larger *F*-value)							
Medic		0.64	0.24		0.22	0.84	0.31
N fert.		0.41	0.02		0.02	<0.01	<0.01
Medic × fert.		0.67	0.77		0.13	0.49	0.28
CV, %		7.51	17.2		10.5	8.62	7.00
Beresford					23 September		
Treatment		19 June	5 Aug.		Grain	Stover	Total corn
0M	0N	1 390	5 420		3 520	4 200	7 770
+M	+N	710	4 130		2 330	3 920	6 240
0M	+N	1 300	8 740		7 210	6 100	13 320
+M	+N	660	5 060		4 930	4 500	9 430
Main effects							
0M		1 350	7 080		5 370	5 150	10 550
+M		685	4 595		3 630	4 210	7 840
	0N	1 050	4 780		2 930	4 060	7 010
	+N	980	6 900		6 080	5 300	11 380
ANOVA (probability of a larger *F*-value)							
Medic		<0.01	0.01		<0.01	0.02	<0.01
N fert.		0.54	0.02		<0.01	<0.01	<0.01
Medic × N fert.		0.34	0.15		0.22	0.11	0.15
CV, %		25.2	26.1		18.6	15.2	16.1

Fertilizer Efficiencies Based on Nitrogen Budgets

At Aurora 1997, fertilizer efficiencies were lower in corn interseeded with medic (23%) than corn alone (39%). These results were attributed to medic competing with corn for N. Different results were observed at Aurora 1998 where fertilizer efficiencies were not influenced by medic (32% in both treatments). The lack of differences at Aurora 1998 was attributed to low medic biomass production. At Beresford 1998, fertilizer efficiencies were similar to those at Aurora 1997 and were 39% for corn interseeded into medic and 54% for corn alone. Competition between medic and corn for N may partially explain why medic reduced biomass production in July at Aurora 1997 and June at Beresford 1998. Competition between legume and nonlegume plants for N was previously reported by Tomm et al. (1995).

Transfer to Medic Nitrogen to Corn

At Aurora 1997, the average δ^{15}N values of medic in the medic–unfertilized treatment (+M/0N) and corn in the no medic–unfertilized treatment (0M/0N) and the medic–unfertilized treatment (+M/0N) were 1.41, 2.42, and 1.89‰, respectively (Tables 4 and 5). The δ^{15}N values of medic suggest that medic N was derived N from several sources, including N fixation, residual N, or some of the 87 kg N ha^{-1} mineralized in the unfertilized treatments. Based on δ^{15}N values, 63 kg N ha^{-1} contained in the corn at harvest in the unfertilized medic treatment was transferred from medic (Eq. [2]) (Shearer and Kohl, 1992). Nitrogen transfer from medic to corn may have resulted from the following events: (i) Medic died in July; and (ii) N contained in the medic was mineralized and taken up by corn. The transfer of N from a legume plant to a nonlegume plant in a pasture has been previously reported by Tomm et al. (1994) and Walley et al. (1996).

At Aurora 1998, medic did not influence N removal by corn or the δ^{15}N value in the grain and stover. These results suggest that corn in the unfertilized plots had a large reliance on the 103 kg N ha^{-1} that was mineralized in the unfertilized plots.

At Beresford 1998, the average δ^{15}N values of medic in the medic–unfertilized treatment (+M/0N), corn in the no medic–unfertilized treatment (0M/0N), and corn in the medic–unfertilized treatment (+M/0N) were 0.262, 2.06, and 1.04‰, respectively. The relatively low δ^{15}N value of the medic (0.262‰) suggests that medic had a relatively small reliance on the 71 kg of N that was mineralized in the unfertilized treatments. Based on δ^{15}N values, 32.5 kg of N contained in corn in the unfertilized treatment was transferred from medic. The N transferred from medic to corn most likely was derived from both above- and belowground portions of the plant.

Table 4. The influence of two medic treatments (+M and 0M) and two N fertilizer rates (+N and 0N) on N contained in the corn at harvest.

		Aurora 1997			Aurora 1998			Beresford 1998		
Medic	Fertilizer	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
		kg N ha^{-1}								
0M	0N	98	20.7	119	94	26	120	40	17	57
+M	0N	78	12.9	91	74	20	94	32	26	57
0M	+N	143	27.6	171	128	40	168	101	33	134
+M	+N	128	22.4	150	131	35	166	71	35	106
Main effects										
0M		121	24.2	145	111	33	144	71	25	96
+M		103	17.7	121	102	28	130	52	31	82
	0N	88	16.8	105	84	23	107	36	22	57
	+N	136	25.0	161	129	37	167	86	34	120
ANOVA (probability of a larger *F*-value)										
Medic		<0.01	<0.01	<0.01	0.24	0.24	0.22	0.06	0.34	0.31
N fert.		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
Medic × N fert.		0.30	0.67	0.45	0.60	0.12	0.09	0.31	0.24	0.53
CV, %		8.95	15.3	9.72	12.2	9.8	9.3	18.5	35.3	28.7

Table 5. The influence of two medic treatments (+M and 0M) and two N fertilizer rates (+N and 0N) on ^{15}N values in grain and stover at harvest.

		Aurora 1997		Aurora 1998		Beresford 1998	
Treatment		Grain	Stover	Grain	Stover	Grain	Stover
		%					
0M	0N	2.20	1.60	2.19	0.83	1.87	2.23
+M	0N	1.93	1.12	1.93	0.75	1.39	0.58
0M	+N	1.44	0.35	1.44	−0.02	0.24	−0.97
+M	+N	1.80	−0.16	1.79	−0.09	−0.04	−1.02
Main effects							
0M		1.82	0.98	1.81	0.41	1.05	0.63
+M		1.87	0.48	1.86	0.33	0.68	−0.22
	0N	2.07	1.36	2.06	0.79	1.63	1.41
	+N	1.62	0.09	1.62	−0.06	0.10	−0.99
ANOVA (probability of a larger *F*-value)							
Medic		<0.01	0.12	0.81	0.74	0.31	<0.01
N fert.		<0.01	<0.01	0.04	0.09	<0.01	<0.01
Medic × N fert.		<0.01	0.96	0.13	0.57	0.35	<0.01
CV, %		11.27	78.9	20.3	175	57.0	205

Medic and Nitrogen Fertilizer Impact on Oat Nitrogen

The impact of N and medic on N cycling was not just limited to the year that the treatments were applied. At Aurora 1997, medic did not influence N contained in oat harvested from the plots in 1998. However, oat harvested from fertilized plots contained 23 kg ha^{-1} more N than oat harvested from unfertilized plots (Table 6). The impact of N fertilizer on N contained in oat was attributed to the remineralization of immobilized N fertilizer contained in soil microbial biomass, corn residue, or medic residues. These findings are conceptually in agreement with those of Clay et al. (1990). Oat grown at Aurora 1998 in the medic and N treatments had similar results.

At Beresford in 1998, oat harvested from plots fertilized with N contained 40.5 kg ha^{-1} more N than unfertilized plots, and plots harvested from medic plots contained 20 kg ha^{-1} more N than nonmedic plots. Findings from the three sites show that interseeding with medic may (Beresford) or may not (Aurora 1997 and 1998) increase N removal by oat in the following year. These findings are in agreement with previous studies that also had mixed results (Utomo et al., 1990; Ebelhar et al., 1984).

Medic and Nitrogen Impacts on Carbon-13 Discrimination in Corn

At Aurora 1998, medic did not influence Δ, and fertilizing with N increased Δ in corn grain from 2.62 to 2.81‰. The lack of differences in Δ due to medic was expected because medic did not impact yields or fertilizer efficiency. Based on the yield and Δ values in the fertilized plots (Table 3), $\delta\Delta_{\text{N stress}}$ (Eq. [8]) was estimated to be −0.0091‰ (percentage loss in yield due to N stress)$^{-1}$.

Similar results were observed at Beresford 1998 where N increased Δ in corn grain from 2.14 to 2.36‰ while interseeding corn with medic did not influence Δ (2.25‰). Care must be used in evaluating Δ because both water and N interact to influence Δ. At Beresford 1998, similar Δ values in medic and nonmedic corn most likely resulted from medic increasing both water and N stress in corn. If this occurred, then Eq. [7] and [8] could be used to separate the water and N effects of medic on corn from each other. However, these equations

Table 6. The influence of two medic treatments (+M and 0M) and two N fertilizer rates (+N and 0N) on oat biomass, mg N kg⁻ oat biomass, N removal, and $\delta^{15}N$.

Treatment		Biomass yield	Biomass N percentage	N removal	$\delta^{15}N$
		kg ha^{-1}	mg N kg^{-1}	kg ha^{-1}	‰
Aurora 1997					
0M	0N	4 470	16.4	94.3	2.21
+M	0N	3 930	16.3	73.8	1.35
0M	+N	5 080	16.4	94.3	1.86
+M	+N	4 840	19.2	103.1	1.86
Main effects	0N	4 200	16.4	84.1	1.78
	+N	4 960	17.8	98.7	1.86
ANOVA (probability of a larger *F*-value)					
Medic		0.10	0.06	0.66	0.15
N fert.		<0.01	0.04	0.01	0.20
Medic × N fert.		0.48	0.20	0.25	0.85
CV, %		9.36	9.20	12.1	31.7
Aurora 1998					
0M	0F	6 127	16.4	99.9	2.55
+M	0F	6 093	15.9	96.8	1.92
0M	+F	5 726	19.8	113.9	2.26
+M	+F	6 160	19.2	117.8	2.27
Main effects	0N	6 110	16.2	98.4	2.24
	+N	5 940	19.5	115.9	2.27
ANOVA (probability of a larger *F*-value)					
Medic		0.65	0.51	0.97	0.27
N fert.		0.71	<0.01	0.07	0.91
Medic × N fert.		0.60	0.99	0.69	0.26
CV, %		14.3	9.50	15.6	23.8
Beresford 1998					
0M	0N	7 090	14.0	99.6	1.10
+M	0N	8 451	14.3	120.3	0.69
0M	+N	7 076	13.5	120.8	0.58
+M	+N	11 320	16.1	180.2	0.25
Main effects					
0M		7 080	13.8	110	0.84
+M		9 890	15.2	150	0.47
	0N	7 770	14.2	110	0.90
	+N	9 200	14.8	150	0.42
ANOVA (probability of a larger *F*-value)					
Medic		0.13	0.01	0.03	0.38
N fert.		0.05	0.17	0.03	0.26
Medic × N fert.		0.69	0.03	0.21	0.92
CV, %		25.2	6.10	23.7	121.2

require that $\delta\Delta_{water\ stress}$ and $\delta\Delta_{N\ stress}$ be known. Based on the only data available (Clay et al., 2001a), $\delta\Delta_{water\ stress}$ in Eq. [8] was estimated to be 0.0117‰ (percentage loss in relative yield)$^{-1}$. Grain yields from Table 3 and Δ presented above were used to estimate that $\delta\Delta_{N\ stress}$ was -0.0042‰ (% yield loss from N stress)$^{-1}$ [= (2.14 − 2.36‰)/(51.8% grain yield loss from N stress)]. By simultaneously solving Eq. [7] and [8] using the total percentage yield loss (TYL) and $\delta\Delta$ (change in Δ in corn due to adding medic) values of 31.6% [yield loss from medic in fertilized treatments = 100(7210 − 4930 kg ha^{-1} grain)/7210 kg ha^{-1} grain)] and zero, respectively, the yield losses due to medic-induced water and N stresses were estimated to be 8.34 (601 kg ha^{-1} grain) and 23.3% (1680 kg ha^{-1} grain), respectively. This analysis suggests that the primary factor causing the yield reduction at Beresford 1998 was a medic-induced N stress in corn. The decrease in fertilizer efficiency and N concentrations in biomass samples, due to medic, at Aurora 1997 and Beresford 1998 support this hypothesis.

CONCLUSION

Medic increased water infiltration at Aurora 1997 and Aurora 1998. The impact of medic on water infiltration was attributed to medic improving soil structure and protecting the soil surface in interrow areas. At two sites where relatively large amounts of medic biomass were produced (Aurora 1997 and Beresford 1998), corn growth was reduced as early as July at Aurora 1997 and June at Beresford 1998. Biomass reductions and reduced N concentrations in biomass samples measured in June and July suggest that a factor other than water stress was responsible for growth reductions. Allelopathic effects of medic on corn were discounted because leaf extracts from medic did not reduce corn seed germination or seedling growth (Vos, 1999). At one site (Aurora 1998), where a relatively small amount of medic biomass was produced, medic did not influence corn yield.

Based on calculated fertilizer efficiencies, $\delta^{15}N$, and Δ, the corn yield losses at Aurora 1997 and Beresford 1998, due to inseeding with medic, were primarily due to N stress and not water stress. The relatively small impact of medic on increased water stress in corn may have resulted from medic increasing water infiltration rates and/or medic utilizing water that otherwise would have been lost to evaporation. Given these findings, additional research is needed to assess if alternative N fertilizer management strategies can be used to reduce the competition between medic and corn for N.

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