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Nitrogen requirements of corn (*Zea mays* L.) as affected by monocropping and intercropping with Alfalfa (*Medicago sativa*)

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Abstract

Intercropping perennials with corn has the potential to improve utilization of the growing season over monocropping corn in regions where a substantial portion of the growing season is too cool for corn growth. The biomass potential and fertilizer N requirements of monocropped corn (*Zea mays*) grown using conventional tillage were compared with those of corn intercropped with alfalfa (*Medicago sativa*) in 1987 and 1988. The intercropped alfalfa was harvested once prior to planting the corn each spring. Rotation effects on and N fertilizer requirements for monocropped corn following these treatments and also following monocropped alfalfa, were evaluated in 1989 and 1990. During the two years of intercropping for which data is presented, the critical intercropped corn biomass (13.05 Mg ha $^{-1}$) estimated using a quadratic-plus plateau model, was close to the monocropped corn biomass (13.01 Mg ha^{-1}), but an estimated 83 kg ha^{-1} more N was required for intercropped corn to reach the critical biomass. Total biomass (intercropped corn and alfalfa) was 25% greater than that of the monocropped corn, and the total N uptake was 55% greater than that by monocropped corn over the two- year period. After rotation to monocropped corn using conventional tillage in 1989, corn biomass averaged over N rates following intercropping or monocropped corn was lower ($P = 0.01$) than following monocropped alfalfa. Critical corn biomass estimated was highest following alfalfa and lowest following monocropped corn, and more N fertilizer was required to attain the critical biomass under continuous monocropped corn in 1989. Corn yields and N uptake values in 1990 were not significantly different among the cropping systems. The N fertilizer replacement values due to intercropping decreased from above 90 kg N ha^{-1} in the first year of rotation to less than 40 kg N ha^{-1} in the second year of rotation. Considering the higher potential for total biomass production and rotation benefit, intercropping is a viable alternative to conventional corn monoculture for forage production.

Introduction

More effectively utilizing the growing season can enhance soil productivity. In regions where a substantial part of the growing season is too cool for warm season crops, staggering component crops by intercropping can utilize the growing season more effectively than sole crops (Hiebsch and McCollum, 1987; Hiebsch et al., 1995). In the coastal Pacific Northwest of the United States where summers are cool and winters are mild, the growing season for cool season crops extends from March through October when soil drainage is adequate. Optimum corn planting dates are not reached until May and corn growth occurs only from May through September. This results in underutilization of the growing season when corn is monocropped.

A perennial forage species such as alfalfa, which is better adapted to the cooler part of the growing season and is normally harvested several times each year, could complement corn to more fully utilize the growing season. Intercropped perennial forages have the potential advantage over corn monocropping of providing year-round ground cover. The potential of such a cropping system to reduce soil erosion and improve soil quality and recovery of residual N fertilizer for groundwater protection has prompted research on growing corn in living mulches (Mt. Pleasant, 1982; Hall et al., 1984; Eberlein et al., 1992; Hesterman et al., 1992). Nitrate leaching in soils with well-established alfalfa is generally low (Peterson and Russelle, 1991). The addition of plant biomass to soil slows the rate of organic matter loss from the soil (Jenkinson and Rayner, 1977; Varvel, 1994).

Sod-forming legumes and non-legumes can be established in corn by interseeding or overseeding without reducing corn yields if appropriate management practices are used (Schaller and Larson, 1956; Pendleton, et al., 1956; Nordquist and Wicks, 1974; Palada et al., 1983). In strip intercropping, the competition for available N and soil moisture between the component crops can be severe (Kurtz et al., 1952) so that their responses to N fertilizer additions may be different from those of sole crops. The degree of competition from intercropped legumes with corn can be reduced by partial or complete suppression of the living mulch particularly where rainfall is limiting and irrigation is not an option (Nicholson and Wien, 1983; Elkins et al., 1979; Granatstein and Kirby, 1986; Box et al., 1980). Yields of corn no-till planted into completely suppressed sod can be equal to yields of corn grown using conventional tillage (Robertson et al., 1976; Scott et al., 1987; Eberlein et al., 1992), although higher (Bennett et al., 1976; Vrabel, 1981; Ebelhar et al., 1984) or lower yields (Triplett, 1962; Imholte and Carter, 1987) have also been reported.

The degree of competition from intercropped legumes with corn may be reduced by narrowing the width of the sod strip (Palada et al., 1983). When the twin-row corn planting pattern on tilled strips is used in conjunction with a narrow width of the sod strip, it is possible that the competition from the legume with corn for N can be further reduced. The twin-row pattern with 1.5 m between each pair of twin rows (Jellum and Kuo, 1990) allows N fertilizer and pesticide treatments to be isolated to reduce the effect on and competition from the intercropped legumes. The wider spacing between each pair of twin rows allows more light to penetrate through the canopy compared to a conventional 0.76-m single-row spacing (Ottman and Welch, 1989). When adequate soil moisture and soil fertility are maintained, yield differences between corn grown in living sods and in conventional tillage can be minimized and benefits from the companion crop realized (Elkins et al., 1979; Hall et al., 1984; Buhler and Mercurio, 1988).

The use of perennial alfalfa as a component crop in corn/alfalfa intercropping eliminates the necessity of annual seeding and N fertilization to sustain its growth. Alfalfa is well-recognized for its capability to fix N and reduce the N fertilizer requirements of the following crop under appropriate soil and environmental conditions (Ebelhar et al., 1982; Legg and Meisinger, 1982; Fox and Piekielek, 1988; Hesterman et al., 1992). Including a legume sod in rotations can also improve soil aeration, water infiltration (Barber, 1972), root activity (Copeland and Crookston, 1992), and mycorrhizal fungi populations (Johnson et al., 1992). The benefits of rotations with monocropped alfalfa might also occur in continuous corn production if alfalfa is intercropped with corn during a portion of a cropping system followed by monocropped corn. The objectives of this study were to determine: 1) the N requirements and biomass potential of corn intercropped with alfalfa using paired rows and strip tillage; and 2) the N requirements of monocropped corn and rotation effects following three years of intercropping compared with corn following three years of monocropped corn or alfalfa.

Materials and methods

Silage corn and alfalfa were intercropped on a Sultan silt loam soil (fine-silty, mixed, non-acid, mesic Aquic Xerofluvent) located on the Washington State University-Puyallup Research and Extension Center near Puyallup, Washington. Alfalfa (var. Saranac) was planted 28 August 1985 for both intercropping and a monoculture stand at a seeding rate of 18 kg ha^{-1}. A sufficient area of monoculture alfalfa was grown to accommodate N treatments for corn following rotation to monocropped corn in 1989. The monoculture alfalfa was harvested in three cuttings each year during 1987 and 1988. The experiment site was kept fallow throughout the growing season before establishing the alfalfa. Although corn was intercropped or monocropped from 1986 to 1988, the response of monocropped corn biomass to N fertilizer in 1986 was minimal and far different than in 1987 and 1988. Because this probably resulted from the experiment site being fallowed in 1985, the 1986 growing season was regarded as an equilibration year for the system, and data were not included in the analysis.

Following alfalfa cutting early in May in 1987 and 1988, 0.6-m wide strips in an east-to-west orientation centered at 1.5 m intervals were sprayed with glyphosate (isopropylamine salt of N- (phosphonomethyl)glycine) at a rate of 2.0 kg ha^{-1} and with alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)-acetamide) at 3 kg ha^{-1} for residual weed control. The herbicide-sprayed strips were fertilized with KCl and Sul-Po-Mag at rates of 240 kg K ha^{-1} and 11 kg S ha^{-1}. The alfalfa between the sprayed strips was fertilized with 30 kg P ha^{-1} as triple superphosphate and 60 kg K ha^{-1} and 22 kg S ha^{-1} as KCl and Sul-Po-Mag. The sprayed strips were tilled to a depth of 8 to 10 cm.

Silage corn (Northrup King PX9903) was planted at a rate of 82,000 seeds ha^{-1} on 17 May 1987 and 14 May 1988 in a paired row pattern centered in the sprayed strips with 0.3 m between rows of the pair. This configuration accommodated the same number of rows as the conventional 0.90-m row spacing for single rows and allowed better light penetration to the alfalfa, better isolation of fertilizer nutrients applied for the corn, and reduced encroachment of alfalfa topgrowth on the corn. Triple superphosphate was banded beside the seed at planting at 67 kg P ha^{-1}. Zero, 150, 200, or 250 kg N ha^{-1} as NH_4NO_3 was applied in a split application with 0 or 67 kg N ha^{-1} applied in the band with the triple superphosphate at the time of planting and the balance applied in a band evenly spaced between the two corn rows of each pair when the corn was about 30 cm tall (V3 development stage). Nitrogen rates were chosen in accordance with the rate recommended by the Washington State University fertilizer guide. Monocropped corn was grown in 0.90-m spacing and with identical treatments except with conventional tillage and without the additional P and K fertilizer and slug control used for the alfalfa intercrop. For comparison purposes, the tillage depth was limited to the same depth as used for the strips in the intercropping.

After emergence, 3 kg ha^{-1} Deadline 40 (4% metaldehyde) was banded on the soil surface between each corn row and the adjacent alfalfa strip for slug control. Dicamba (dimethylamine salt of dicamba (3,6-dichloro-anisic acid)) was applied at 0.25 kg ha^{-1} over the corn strips in June for broadleaf weed control. Supplemental water was applied by sprinkler irrigation during the latter part of July and August to prevent soil moisture stress. Corn ear leaves were sampled in mid-August, dried at 60°C for 72 h and ground prior to N analysis. The above-ground biomass of corn was harvested on 22 September 1987 and 3 October 1988. Corn plants were sampled by cutting the above ground biomass from 1.5 m of both rows of a pair in each plot, weighed, and chopped using a forage harvester. One kilogram subsamples were removed from the well-mixed chopped plant material, dried for 72 h at 60°C for dry matter determination and ground prior to N analysis. Plant tissue samples were digested in H_2SO_4 and H_2O_2 at 400°C prior to analysis for N concentration by distillation (Keeney and Nelson, 1982). Cropping systems (intercrop or monocrop) were arranged in a randomized complete split-plot design with N fertilizer rates as the sub-plot treatments. Each treatment was replicated three times. Subplots were 6.0 m wide and 9.0 m long. Following analysis of variance, multiple paired comparisons were made using the New Duncan's Multiple Range Test (SAS Institute, 1985).

Late in April 1989 all plots including the monoculture alfalfa established in 1985 were plowed and corn was monocropped for two years in single rows (0.9 m). The plots were first plowed with a moldboard plow to a depth of about 25 cm and then disked twice in all cropping systems. Corn was planted at the same rate as used before, but in a north-to-south direction so that the variation resulting from the alternating alfalfa and tilled strips would be incorporated into the treatments. Nitrogen fertilizer rates were reduced to 0, 67, 133, and 200 kg N ha^{-1} as NH_4NO_3. The corn was harvested by cutting all of the plants in 3.0 m of a single row on 25 September in both 1989 and 1990. Biomass data were fit to a quadratic-plus-plateau model (Ihnen and Goodnight, 1988) for the determination of critical corn biomass and N fertilizer requirements.

Results and discussion

N effects on monocropped and intercropped corn in 1987 and 1988

Cropping systems affected the N uptake by corn, but not N concentration in the harvested corn or corn biomass (Table 1) over the period 1987 to 1988. Nitrogen fertilizer addition significantly increased corn biomass and N uptake (Figure 1) in the harvested corn in both cropping systems. In the intercropping system, the degree of competition between the intercropped corn and alfalfa varied with time during the growing season. Well-established alfalfa can be very competitive for available soil N when intercropped with corn

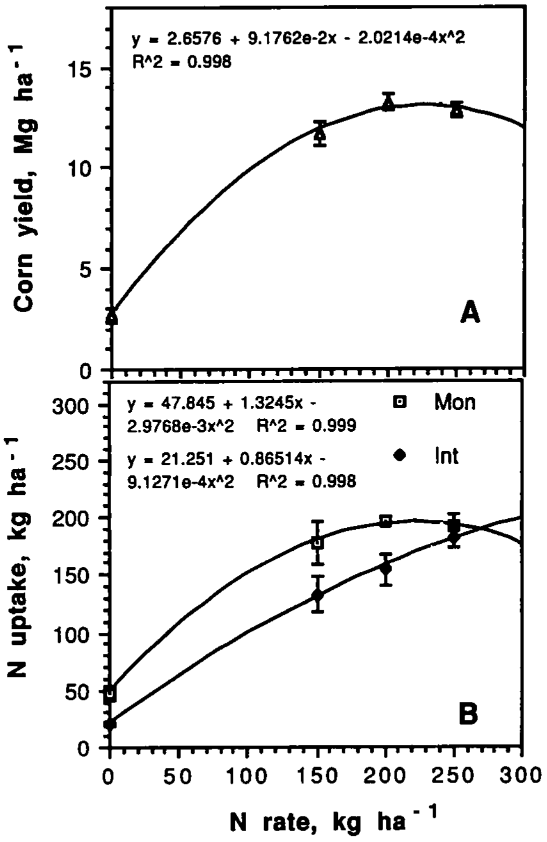

Figure 1. The response of (a) corn biomass, and (b) N uptake averaged over 1987 and 1988 as affected by N fertilizer rate. Bars indicate the standard error.

(Pendleton et al., 1956; Vrabel, 1981; Mt. Pleasant, 1982; Eberlein et al., 1992). Our observation was that this was not a problem early in the growing season. The strips had been tilled prior to planting the corn, and the tilled strips were wide enough to prevent shading by the alfalfa strips following regrowth. Tilling also temporarily eliminated competition from alfalfa roots with the developing corn plants.

As the season progressed, the developing corn roots intermingled with those of alfalfa. Competition for N by corn and alfalfa roots could restrict the availability to the intercropped corn of mineralized soil N (Kaspar and Bland, 1992), which constitutes 33 to 60% of N taken up by corn, depending on N rate and tillage (Jokela and Randall, 1987). The N concentration in the ear leaves averaged over all N rates and years was slightly lower (P = 0.05) in the intercropped corn (23.7 g N kg^{-1}) than in the monocropped corn (25.3 g N kg^{-1}), although the difference in N concentrations in the plants between monocropped and intercropped corn was no longer significant at harvest (Table 1).

The biomass of intercropped corn was not different (P = 0.05) from that of monocropped corn (Figure 1a). However, the N fertilizer requirement to attain the critical biomass, estimated using the quadratic-plus-plateau model, was 268 kg N ha^{-1} for intercropped corn based on the entire land area, as compared to 185 kg N ha^{-1} for monocropped corn. These N fertilizer rates estimated were the same as those estimated by the quadratic model (Table 2). The quadratic-plus-plateau model identifies a critical biomass and corresponding N fertilizer rate that occurs at the convergence point of the quadratic and plateau portions of the response curve (Cerrato and Blackmer, 1990). The higher N fertilizer requirement for critical biomass would be an additional cost for the intercropping system. The estimated critical monocropped corn biomass (13.01 Mg ha^{-1}) was no different from that of intercropped corn (13.05 Mg ha^{-1}) averaged over the two-year period (Table 2). Critical corn biomass identified by the quadratic-plus-plateau model were nearly identical to maximum biomass determined using a quadratic model alone (Table 2).

The N concentration in the harvested corn tissue averaged over all N rates was 12.6 g N kg^{-1} for monocropped corn and 10.4 for intercropped corn in 1987 and 15.5 for monocropped corn and 14.9 for intercropped corn in 1988. Higher N concentrations in monocropped corn resulted in its greater (P = 0.05) N uptake compared to that by intercropped corn (Figure 1b). The above-ground biomass of intercropped corn accumulated 120 kg N ha^{-1} as compared to 153 kg N ha^{-1} for monocropped corn averaged over N rates and years. Nitrogen uptake is more sensitive than corn yields to N fertilization in soil (Hesterman et al., 1992). However, N uptake by corn in the two cropping systems at the highest N fertilizer rate was similar (Figure 1b).

The slight reduction in N uptake at low N rates and increased N fertilizer requirements to reach the critical biomass (Table 2) is a drawback for intercropping corn with alfalfa. However, for forage production , the alfalfa harvested early in the spring prior to planting corn should be included in determining the overall effect of the intercropping system on biomass production. When the biomass and N uptake from the alfalfa cuttings taken in 1987 and 1988 prior to planting the corn were added to the critical corn biomass, the total annual biomass production of intercropped corn and alfalfa averaged over the two years (16.32 Mg ha^{-1})

Table 1. Analysis of variance for the effects of N rate and cropping system (corn monocropping and intercropping) on corn biomass, N concentration, and N uptake at harvest in 1987 and 1988.

Source of variation	F value Biomass	N concentration	N uptake
Cropping System (CS)	17.12 NS	9.21 NS	36.69*
N rate	145.26***	6.49**	88.87***
N rate × CS	1.40 NS	2.63 NS	1.69 NS
Year	2.24 NS	53.56*	3.23 NS
Year × CS	0.19 NS	90.89*	11.89 NS

*, **, *** significant at P = 0.05, 0.01, 0.001, respectively; NS = not significant.

Table 2. The coefficients for the quadratic equation and estimated critical corn biomass and N fertilizer rate

	Quadratic parameters a	b	c	Y max	*Critical Values* Biomass	N rate	R^2
					Mg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
1987–1988							
MC*	3.64	9.73×10^{-2}	-2.45×10^{-4}	13.31	13.01	185	1.000
IC	1.66	8.47×10^{-2}	-1.58×10^{-4}	13.05	13.05	268	0.998
1989							
MC	10.66	5.27×10^{-2}	-1.37×10^{-4}	15.74	15.73	192	0.999
IC	12.56	5.93×10^{-2}	-1.95×10^{-4}	17.07	16.84	147	0.993
MA	16.99	1.73×10^{-2}	-5.78×10^{-5}	18.28	18.20	141	0.997
1990							
MC	11.50	4.91×10^{-2}	-9.03×10^{-5}	18.18	18.18	272	0.889
IC	13.29	3.07×10^{-2}	-1.35×10^{-5}	—	—	—	0.971
MA	14.04	2.42×10^{-2}	-4.38×10^{-5}	17.38	17.38	276	0.904

* MC = monocropped corn; Int = intercropped corn; MA = monocropped alfalfa.

was 25% higher than that of the monocropped corn (13.01 Mg ha^{-1}). The average total N uptake in the intercropped corn and alfalfa (237 kg N ha^{-1}) was about 55% greater than the average N uptake in the monocropped corn (153 kg N ha^{-1}). Repeated cutting of intercropped alfalfa has been shown to have no adverse effects on corn yield (Pendleton et al., 1956). If specialized machinery can be developed to harvest the intercropped alfalfa during the mid- growing season, the total biomass production and N uptake in the intercropping would be further increased.

Rotation and N effects on corn in 1989 and 1990

Both cropping system and N rate affected corn biomass following rotation of intercropped corn and monocropped alfalfa to monocropped corn in 1989 and 1990. Because the cropping system by year interaction was highly significant (P = 0.001) for corn biomass and N uptake (P = 0.01), the corn growth responses to cropping system and N rate were illustrated by year.

In 1989, the corn biomass averaged over N rates was lower (P = 0.01) following intercropping (15.58 Mg ha^{-1}) and monocropped corn (13.87 Mg ha^{-1}) than following monocropped alfalfa (17.91 Mg ha^{-1}). Nitrogen uptake by corn was higher (P = 0.05) following monocropped alfalfa (206 kg N ha^{-1}) than following intercropping (169 kg N ha^{-1}) or monocropped corn (155 kg N ha^{-1}) (Table 3). The biomass response to N fertilizer of corn following monocropped alfalfa was typical in that the magnitude of the response was relatively small (Figue 2a). The corn biomass without any N fertilizer addition was 93% of the critical biomass. With no N fertilizer addition, corn biomass following monocropped alfalfa was 33% greater than following intercropped corn and 60% greater than following monocropped corn; N uptake by corn following alfalfa was 73% greater than that fol-

Table 3. The effect of N fertilizer rate and cropping system on corn N concentation and N uptake in 1989 and 1990.†

Treatment	1989		1990	
	N conc.	N uptake	N conc.	N uptake
	g kg^{-1}	kg N ha^{-1}	g kg^{-1}	kg N ha^{-1}
N rate				
0 kg N ha^{-1}	10.0 c	137 c	11.4 b	149 c
67 kg N ha^{-1}	10.8 b	171 b	11.3 b	179 b
133 kg N ha^{-1}	11.4 b	193 a	11.9 ab	199 b
200 kg N ha^{-1}	12.4 a	206 a	12.6 a	231 a
Cropping system (CS)				
MC	10.8 a	155 b	12.0 a	181 a
Int	11.0 a	170 b	11.4 a	192 a
MA	11.5 a	206 a	12.1 a	193 a
ANOVA	F value			
CS	2.56 NS	21.76 **	1.48 NS	1.56 NS
N rate	14.58 ***	19.03 ***	3.92 *	14.08 **
CS X N rate	1.69 NS	1.42 NS	0.98 NS	0.69 NS

† MC = monocropped corn; Int = intercropped corn; MA = monocropped alfalfa
Numbers followed by the same letter within each row are not significantly different at $P = 0.05$ by Duncan's Multiple Range Test.
*, **, *** significant at $P = 0.05, 0.01, 0.001$, respectively; NS = not significant

lowing monocropped corn. The corn biomass without N fertilizer addition was much higher in 1989 than in the previous two years. This probably was related to the deeper plowing to a depth of 25 cm for the entire field, instead of the shallow tillage (10 cm) in the previous two years, and increased soil N availability.

The N fertilizer replacement value estimated based on the biomass response to the preceding legume was 93 kg N ha^{-1} in the intercropping system. The value could not be estimated for corn succeeding alfalfa monocropping because the corn biomass with no N fertilizer addition exceeded the maximum corn biomass with N fertilization in the continuous monocropped corn system. A rotation effect occurred beyond simply increased N availability from the incorporated alfalfa residues. Soil aeration, water infiltration and mycorrhizal activity can be improved by including legumes in crop rotations (Barber, 1972; Copeland and Crookston, 1992; Johnson et al., 1992). Nitrogen replacement values following alfalfa typically exceed 100 kg N ha^{-1} (Bruulsema and Christie, 1987; Fox and Piekielek, 1988).

Critical corn biomass identified by the quadratic-plus-plateau model in 1989 was higher for corn following intercropping or monocropped alfalfa than following monocropped corn (Table 2). The critical N fertilizer rate was higher for corn following monocropped corn than for corn following intercropping or monocropped alfalfa (Table 2). Nitrogen concentrations in the harvested corn tissue increased with increasing N rates but were not different (P = 0.05) among the cropping systems (Table 3). In 1990, N rate (Figure 2b) (P = 0.001) and cropping system (P = 0.05) were significant factors affecting corn biomass production. Averaged over all N rates corn biomass was highest following intercropping (16.80 Mg ha^{-1}), intermediate following monocropped alfalfa (15.78 Mg ha^{-1}) and lowest following continuous corn monocropping (15.00 Mg ha^{-1}). As with N concentration in the harvested corn, N uptake was affected by N fertilizer rate but not by cropping system (Table 3). Because N uptake is more sensitive to soil N availability (Hesterman et al., 1992), the greater increase in corn biomass in the second year following rotation from intercropping likely involved factors other than just N availability. The N fertilizer replacement value in 1990 decreased to 58 kg N ha^{-1} following alfalfa monocropping and 39 kg N ha^{-1} following intercropping. More N from alfalfa is available to corn in the first year after incorporation (Harris and Hesterman, 1990). Close to

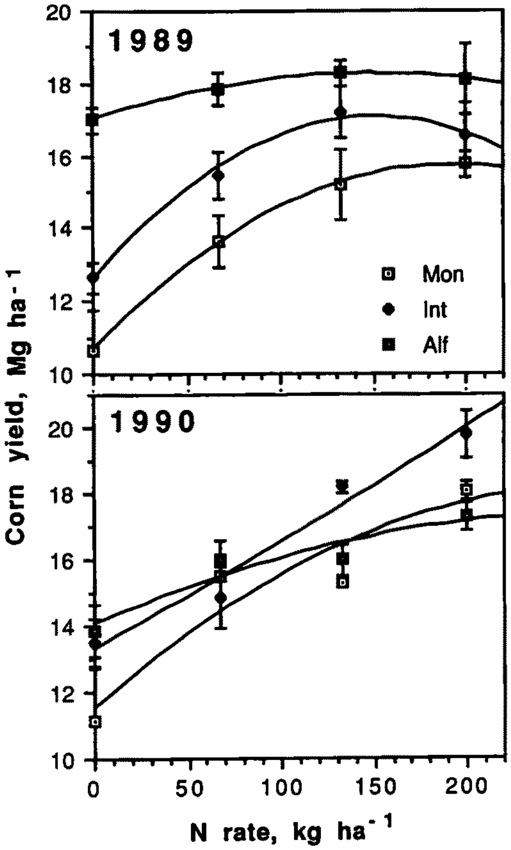

Figure 2. The response of corn biomass to N fertilizer as affected by cropping system in (a) 1989 and (b) 1990. Bars indicate the standard error.

50% of alfalfa N incorporated into soil is assimilated into soil organic N fraction (Ladd and Amato, 1986; Harris and Hesterman, 1990), and its slow release from this fraction reduces the impact of incorporated alfalfa on crop yields after the first year (Fox and Piekielek, 1988).

The critical N fertilizer requirements estimated by the model (Table 2) were substantially increased to levels well above those actually applied in 1990 both for corn following monocropped alfalfa and continuously monocropped corn. The critical N fertilizer rate could not be evaluated for corn following intercropping because the linear response of corn biomass to N rate precluded identification of the maximum biomass.

Conclusions

Corn planted in paired rows into tilled strips of established alfalfa sod with adequate soil moisture had the same biomass potential as monocropped corn grown using conventional tillage and row spacing. Nitrogen fertilizer requirements for critical corn biomass for intercropped corn were higher than for monocropped corn, possibly due to competition from alfalfa roots that reduced the availability of soil N. Both the N concentration in the ear leaf and N accumulation in the harvested corn were significantly lower in the intercropped corn than in the monocropped corn. However, compared to corn monocropping, intercropping produced 25% more total biomass and 55% more N uptake when the cutting of alfalfa prior to corn planting and its N uptake were included with the corn biomass and N uptake.

Rotation of monocropped alfalfa to monocropped corn in 1989 produced higher corn yields and N uptakes than continuously monocropped corn or intercropped corn. This was attributed in part to increased soil N availability after the alfalfa residue was incorporated into the soil. The fertilizer replacement value for the intercropping system decreased from 93 kg N ha^{-1} in 1989 to 39 in 1990. The greater biomass response to N fertilizer for corn in the second year after rotation from intercropped corn than for corn in the other cropping systems could not be clearly explained.

Considering the greater total biomass production potential and rotation benefit, intercropping is a viable alternative to conventional corn monoculture for forage production. However, information on the additional costs incurred due to increased intensity of crop management, the variability in the value of the forage produced, and potential benefits for reducing N leaching is also needed before adopting the intercropping system for forage production. Such an analysis is required to determine the maximum economic yields.

References

Barber SA (1972) Relation of weather to the influence of hay crops on subsequent corn yields on a Chalmers silt loam. Agron J 64: 8–10

Bennett OL, Mathias EL, and Sperow CB (1976) Double cropping for hay and no-tillage corn production as affected by sod species with rates of atrazine and nitrogen. Agron J 68: 250–254

Box JE Jr, Wilkinson SR Dawson RN, and Kozachyn J (1980) Soil water effects on no-till corn production in strip and completely killed mulches. Agron J 72: 797–802

Bruulsema TW and Christie BR (1987) Nitrogen contribution to succeeding corn from alfalfa and red clover. Agron J 79: 96–100

Buhler DD and Mercurio JC (1988) Vegetation management and corn growth and yield in untilled mixed-species perennial sod. Agron J 80: 454–462

Cerrato ME and Blackmer AM (1990) Comparison of models for describing corn yield response to nitrogen fertilizer. Agron J 82: 138–143

Copeland PJ and Crookston RK (1992) Crop sequence affects nutrient composition of corn and soybean grown under high fertility. Agron J 84: 503–509

Ebelhar SA, Frye WW and Blevins RL (1984) Nitrogen from legume cover crops for no-tillage corn. Agron J 76: 51–55

Eberlein CV, Sheaffer CC, and Oliveira VF (1992) Corn growth and yield in an alfalfa living mulch system. J Prod Agric 5: 332–339

Elkins DM, Vandeventer JW, Kapusta G and Anderson MR (1979) No-tillage maize production in chemically suppressed grass sod. Agron J 71: 101–105

Fox RH and Piekielek WP (1988) Fertilizer N equivalence of alfalfa, birdsfoot trefoil, and red clover for succeeding corn crops. J Prod Agric 1: 313–317

Granatstein D and Kirby E (1986) Intercropping forage legumes with maize under two row patterns. Farming systems research project, Research Division Report RD-R-72, Ministry of Agriculture, Maseru, Lesotho

Hall JK, Hartwig NL and Hoffman LD (1984) Cyanazine losses in runoff from no-tillage corn in "living" and dead mulches vs. unmulched, conventional tillage. J Environ Qual 13: 105–110

Harris GH and Hesterman OB (1990) Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen -15. Agron J 82: 129–134

Hesterman OB, Griffin TS, Williams PT, Harris GH and Christenson DR (1992) Forage legume-small grain intercrops: nitrogen production and response of subsequent corn. J Prod Agric 5: 340–348

Hiebsch CK and McCollum RE (1987) Area-X-time equivalency ratio: A method for evaluating the productivity of intercrops. Agron J 79: 15–22

Hiebsch CK, Tetio-Kagho F, Chirembo AM and Gardner FP (1995) Plant density and soybean maturity in a soybean-maize intercrop. Agron J 87: 965–969

Ihnen LA and Goodnight JH (1988) The NLIN procedure. In SAS/STAT user's guide, release 6.03 edition, SAS Inst Inc Cary, NC

Imholte AA and Carter PR (1987) Planting date and tillage effects on corn following corn. Agron J 79: 746–751

Jellum EJ and Kuo S (1990) Effects of corn row pattern and intercropping with legumes on silage corn. J Prod Agric 3: 545–551

Jenkinson DS and Rayner JH (1977). The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci 123: 298–305

Johnson NC, Copeland PJ, Crookston RK and Pfleger FL (1992) Mycorrhizae: possible explanation for yield decline with continuous corn and soybean. Agron J 84: 387–390

Jokela WE and Randall GW (1987). A nitrogen-15 microplot design for measuring plant and soil recovery of fertilizer nitrogen applied to corn. Agron J 79: 322–325

Kaspar TC and Bland WL (1992) Soil temperature and root growth. Soil Sci 154: 290–299

Keeney DR and Nelson DW (1982) Nitrogen-inorganic forms. In: AL Page et al (eds). Methods of soil analysis, Part 2. 2nd ed. Agronomy 9: 643–698. Madison, Wisc: American Society of Agronomy

Kurtz T, Melsted SW and Bray RH (1952) The importance of nitrogen and water in reducing competition between intercrops and corn. Agron J 44: 13–17

Ladd JN and Amato M (1986) The fate of nitrogen from legume and fertilizer sources in soils successively cropped with wheat under field conditions. Soil Biol Biochem 18: 417–425

Legg JO and Meisinger JJ (1982) Soil nitrogen budgets. In: FJ Stevenson (ed) Nitrogen in agricultural soil, Agronomy 22: 503–566. Madison, Wisc: American Society of Agronomy

Mt. Pleasant J (1982) Corn polyculture systems in New York. M.S. thesis. Cornell Univ., Ithaca, NY

Nicholson AG and Wien HC (1983) Screening of turfgrasses and clovers for use as living mulches in sweet corn and cabbage. J Am Soc Hort Sci 108: 1071–1076

Nordquist PT and Wicks GA (1974) Establishment methods for alfalfa in irrigated corn. Agron J 66: 377–380

Ottman MJ and Welch LF (1989) Planting patterns and radiation interception, plant nutrition concentration and yield in corn. Agron J 81: 167–174

Palada MC, Ganser S, Hoffstetter R, Volak B, and Culik M (1983) Association of interseeded legume cover crops and annual row crops in year-round cropping systems. In: W Lockeretz (ed) Environmentally sound agriculture pp. 202–231 Praeger Special Studies. Praeger Sci, New York, NY

Pendleton JW, Jackobs JA, Slife FW and Bateman HP(1956) Establishing legumes in corn. Agron J 49: 44–48

Peterson TA and Russelle MP (1991) Alfalfa and the nitrogen cycle in the corn belt. J Soil and Water Cons. 46: 229–235

Robertson WK, Lundy HW, Prine GM and Currey LW (1976) Planting corn in sod and small grain residues with minimum tillage. Agron J 68: 271–274

SAS Institute (1985) SAS user's guide. Statistics, version 5. SAS Institute, Cary, NC.

Schaller FW and Larson WE (1956) Effect of wide spaced corn rows on corn yields and forage establishment. Agron J 48: 271–276

Scott TW, Mt. Pleasant J, Burt RF and Otis DJ (1987) Contributions of ground cover, dry matter, and nitrogen from intercrops and cover crops in a corn polyculture system. Agron J 79: 792–798

Triplett GB Jr (1962) Intercrops in corn and soybean cropping systems. Agron J 54: 106–109

Varvel G (1994) Rotation and nitrogen fertilization effects on changes in soil carbon and nitrogen. Agron J 86: 319–325

Vrabel TE (1981) The use of legumes as living mulch crops with sweet corn (Zea mays L.) feasibility studies. M.S. thesis. Cornell Univ., Ithaca, NY