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Research article

Sweet corn production and efficiency of nitrogen use in high cover crop residue

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Abstract – In the humid, temperate mid-Atlantic area of the USA, crop production that leaves the soil uncovered can lead to undesirable soil and nutrient losses to the surrounding Chesapeake Bay watershed. To cope with this issue, winter annual cover crops could provide soil cover both during winter months and, as surface residue in no-tillage cropping systems, during summer months. Legume cover crops such as hairy vetch can produce abundant biomass and N by the time summer crops are planted in spring. Although N mineralized from a legume cover crop can contribute to meeting the N requirement of crops such as corn, it also may not be used efficiently by crops and could be lost into the local environment. This research was conducted to determine whether hairy vetch or a hairy vetch-rye mixture that was allowed to produce high levels of biomass with a high N content (200 to 250 kg/ha) could meet the N requirements of no-tillage sweet corn and to determine the efficiency of N use relative to that of fertilizer N. Our results show that marketable yield of sweet corn was approximately doubled by hairy vetch in 2 of 3 years compared to an unfertilized, no-cover crop control. However, in 2 of 3 years, hairy vetch and the vetch-rye mix reduced yield by 19 and 34%, respectively, compared to a no-cover crop control with fertilizer N. Reduced plant population that reduced the number of ears per ha accounted for the yield reduction by these cover crops compared to the fertilized no-cover crop control. Fertilizer N was 1.5 to 2 times more efficient than hairy vetch at producing sweet corn ear mass per unit of N input but combinations of fertilizer N with cover crops were less efficient than either alone. Results suggest that growing sweet corn without tillage in high biomass levels of cover crops can interfere with crop establishment, reduce the efficiency of crop production, and allow for potentially high N losses into the environment.

cover crops / nitrogen use efficiency / sweet corn / *Zea mays* L. / hairy vetch / *Vicia villosa* Roth / rye / *Secale cereale* L.

1. INTRODUCTION

Recent interest in cover crops has been motivated by the increase in the cost of commercial fertilizers, the decline in soil fertility and organic matter associated with many vegetable farming practices, and the loss of soil, nutrients and pesticides that become major contaminants to water sources. Use of cover crops in no-tillage production systems can enhance sustainable production by reducing soil and nutrient losses (Shipley et al., 1992; Rice et al., 2001), improving soil physical and biological properties (McVay et al., 1989), retaining soil moisture (Clark et al., 1995), suppressing weeds (Burgos et al., 1996; Carrera et al., 2004), and reducing production costs and increasing profitability (Abdul-Baki and Teasdale, 2007). Hairy vetch is a winter annual legume that is particularly suited as a cover crop for production in humid, temperate climates with moderate winters (Abdul-Baki and Teasdale, 2007). Hairy vetch can be planted in the fall after a cash crop, establish and provide ground cover before winter, and produce a high biomass of viney vegetation with a low C/N ratio and a high N content before a cash crop is planted in the following spring (Ranells and Wagger, 1996; Kuo et al., 1997; Teasdale et al., 2004). After desiccation, this cover crop vegetation can meet a substantial portion of the N requirement of high-N-requiring crops such as corn and allow for a substantial reduction in fertilizer N inputs (McVay et al., 1989; Decker et al., 1994). Several studies have shown that hairy vetch residue decomposes rapidly after desiccation in humid climates and that the majority of N in hairy vetch residue may be released within one month and almost all within a growing season (Ruffo and Bullero, 2003; Ranells and Wagger, 1996). This can also lead to significant N losses to the environment through leaching or denitrification (Rosecrance et al., 2000).

A hairy vetch-rye cover crop mixture may be preferred to a hairy vetch monoculture (Sainju et al., 2005). The mixture can produce higher biomass yield with a higher overall C/N ratio than that of hairy vetch alone (Teasdale and Abdul-Baki,

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1998). The hairy vetch component of the mixture can reduce the N requirement for crops such as corn (Decker et al., 1994) but the rye component develops a more extensive root system that protects soil and captures residual N in fall and winter (Shipley et al., 1992) and provides a slower decomposing surface mulch in summer (Ranells and Wagger, 1996). This mixture has been shown to provide greater environmental benefits by capturing more nitrates and by reducing potential N losses from leaching and denitrification compared to a legume monoculture (Rosecrance et al., 2000).

Although there is a vast literature on corn responses to cover crops, there has been less research conducted on sweet corn response. Several authors have shown that sweet corn following hairy vetch has similar yield to N-fertilized sweet corn without cover crop (Burgos and Talbert, 1996; Cline and Silvernail, 2002; Carrera et al., 2004). Cline and Silvernail (2002) showed that sweet corn following hairy vetch had similar yields with or without fertilizer N for two years, but that after three years with continuous use of hairy vetch in the same plots, fertilizer N was required in addition to hairy vetch to maintain maximum yield. Cherr et al. (2006) showed that sweet corn yield was higher using high rates of fertilizer N than with a combination of lower rates of N plus one of several legume cover crops.

The sweet corn season is shorter than that of field corn because the marketable ears are harvested earlier, when kernel sugar content is optimal, than corn grain which are not harvested until kernels are filled and sufficiently dried for mechanical harvest. A shorter season could reduce the N requirement and create the potential of meeting this requirement with a fully developed hairy vetch or hairy vetch-rye mixture with maximum N content. However, the shorter growing season could also lead to high rates of N leaching after harvest, even at recommended fertilizer N rates (Brandi-Dohrn et al., 1997). The objectives of this research were to (1) determine the impact of hairy vetch and hairy vetch-rye cover crops that were allowed to develop maximum N content on sweet corn yield, and (2) determine the efficiency of nitrogen use for sweet corn production using cover crop and/or fertilizer N sources. We hypothesized that yield of sweet corn would be similar with hairy vetch-based cover crops in comparison with a no-cover crop treatment with recommended fertilizer N. We also hypothesize that the yield per N input efficiency of sweet corn production (using the no-cover crop treatment without fertilizer N as a base level) would be greater when N was applied as fertilizer than when derived from cover crop decomposition.

2. MATERIALS AND METHODS

2.1. Field experimental methods

A three-year, 2003–2005, field experiment was conducted at the USDA-ARS Beltsville Agricultural Research Center, Beltsville, Maryland, on a Matawan-Hammonton loamy sand and Ingleside-Hammonton loamy sand soil. The field had not been planted to corn for at least 3 years before this experiment began. The experimental design was a split-block design with eight replications. The first whole plot was three cover crop treatments (hairy vetch, a hairy vetch-rye mixture, and no cover crop) arranged in strips across each block. The cover crop strips were split by two cover crop killing methods, mowing or rolling, that were 6 corn rows wide (4.6 m) and ranged from approximately 30 to 60 m long depending on the block. A second whole plot, laid out in strips perpendicular to the cover crop, was treated with or without fertilizer N. An irrigation factor was initially designed into the experiment but, since adequate rainfall was received and there were no extended droughty periods during these three years (data not shown), this treatment was dropped resulting in eight instead of four blocks. Each year, the same treatments were applied to the same plots. Major operation and data collection dates are listed in Table I. After ear harvest, the corn stalks were harvested for silage and removed from the field in preparation for planting cover crops for the subsequent year. The experimental site was disked before planting the cover crops in mid-September. Hairy vetch seed was inoculated and planted at 45 kg/ha and the rye component of vetch-rye mixture was planted at 45 kg/ha. Cover crops were grown until high levels of biomass were produced in spring (Tab. II).

Table I. Field operations and data collection for no-tillage sweet corn production at Beltsville, Maryland.

Operation		Growing Season 2003	2004	2005
Plant cover crops in preceding year		19 Sept.	19 Sept.	14 Sept.
Apply paraquat to no cover plots		4 April	20 April	13 April
Cover crop biomass collection		17 June	14 May	9 May
Plant sweet corn		17 June	17 May	9 May
Mow or roll cover crops		17 June	17 May	9 May
Broadcast N application		17 June	17 May	9 May
Apply herbicide		17 June	17 May	9 May
Sidedress N application		21 July	18 June	16 June
Corn population determination		8 July	8 June	8 June
Cover crop residue biomass	1st	8 July	8 June	1 June
	2nd	30 July	9 July	27 June
	3rd	20 Aug.	30 July	19 July
Corn biomass collection	1st	8 July	8 June	–
	2nd	30 July	9 July	28 June
	3rd	20 Aug	30 July	20 July
Corn first ear harvest		4 Sept.	9 Aug.	2 Aug.
Corn second ear harvest		–	–	8 Aug.

During the first week of April of each year, the no-cover crop plots were sprayed with 0.56 kg ai/ha of paraquat and 0.25% of nonionic surfactant to eliminate vegetation (Tab. I). 'Silver Queen' sweet corn was planted at a target population of 59 000 seeds ha^{-1} in 76 cm rows using a no-till, 4-row planter (John Deere model 7200, John Deer and Co., Frederick, MD). Phosphorus and potassium were applied to all plots at a rate of 34 kg/ha of P_2O_5 and K_2O, respectively, each at planting. Immediately following corn planting, the designated half of each cover crop plot was either mowed using a high-speed flail mower (Alamo Corp., Seguin, Texas) that cut the plants about 5 cm above the soil surface, or rolled using a unit built by the authors to flatten and crimp the cover crop stems without disturbing the soil. Following killing the cover crops,

Table II. Cover crop biomass and nitrogen content at planting and cover crop decomposition at 9 weeks after planting. Decomposition refers to the amount of biomass present at planting when cover crops were terminated minus the amount remaining at 9 weeks after planting expressed as a percentage of the amount at planting. Nitrogen released refers to the corresponding loss of N from cover crop tissue between planting and 9 weeks after planting.

		At planting		At 9 weeks after planting		
Year	Cover crop	Biomass (Mg/ha)	Nitrogen (kg/ha)	Biomass decomposition (%)	Nitrogen released (%)	Nitrogen released (kg/ha)
2003	Hairy vetch	5.75	201	42	59	119
	Hairy vetch + Rye	11.17	259	68	66	171
2004	Hairy vetch	4.67	197	57	80	157
	Hairy vetch + Rye	8.95	252	76	85	213
2005	Hairy vetch	5.45	228	71	84	191
	Hairy vetch + Rye	10.21	249	60	73	183

84 kg/ha N was broadcast as ammonium nitrate to designated plots. The rest of the N (90 kg/ha) was applied as side dressing when the crop reached the 6-leaf stage. All plots were sprayed with 1.48 kg ai/ha of atrazine, 1.14 kg ai/ha of S-metolachlor, 0.53 kg ai/ha of paraquat, and 0.25% nonionic surfactant following planting, cover crop mowing/rolling, and broadcast fertilizing. Asana XL [(s)-cyano(3-phenoxy phenyl) methyl (s)-4-choloro-alpha-(methyl ethyl) benzene acetate] was applied at a rate of 0.0187 kg ai/ha to control corn earworm (*Helicoverpa zea* Boddie) in 2003.

Immediately before seeding the corn, 0.25 m^2 samples of above-ground cover crop biomass were taken from each block, dried at 65 °C, weighed, and ground to pass through a 40-mesh screen for N determination. Additional 1 m^2 grab samples of the surface cover crop residue were taken from each plot at 3, 6, and 9 weeks after killing the cover crops for determination of biomass and N content (Ruffo and Bollero, 2003). Care was taken to remove stones and soil from the residue before biomass and N determination.

Within each plot, an area including a 9 m length of the inner 3 rows was reserved for ear yield collection. Corn population was determined from these inner three rows about 3 weeks after planting. Corn plants were sampled at 3, 6, and 9 weeks after planting from areas adjacent to the designated yield areas at the same time cover crop residue samples were taken. Four representative plants were taken at the first sampling date, two plants for the second sampling date, and one plant for the third sampling date. The plants were washed, dried at 65 °C, weighed, and ground for N determination. Data on weight and number of marketable ears were collected from the yield sections of the inner 3 rows of each plot. One harvest was made in 2003 and 2004 because the treatments matured at the same time. Two harvests were made in 2005, due to differences in maturity time among treatments.

2.2. Analysis

An analysis of variance for a split-block design was conducted on sweet corn biomass, N content, and yield component variables using a mixed model procedure (PROC MIXED, SAS version 9.1, SAS Institute, Cary, NC) with cover crop and nitrogen as fixed effects and block, block × cover crop, and block × nitrogen as random effects. Mean separations were determined by the probability of differences ($P < 0.05$) of least squared means using the PDIFF option of the LSMEANS statement. To test for the effect of cover crop management (mowing or rolling), an analysis of variance was conducted using only data from treatments with cover crops (data from the no-cover crop treatment were excluded). A mixed model was used for this analysis with cover crop, nitrogen, and cover crop management as fixed effects and block, block × cover crop, and block × nitrogen as random effects.

The efficiency of sweet corn ear yield production per unit N input either from fertilizer or cover crop was determined by the differential between the yield of a specified treatment receiving N inputs and the yield of the unfertilized no-cover crop treatment in a given year. Efficiency of nitrogen use was determined by the ratio of the yield differential attributed to N inputs and the amount of the N input,

$$\textit{Efficiency} = \frac{Y_n - Y_0}{\mathrm{N}_i}$$

where Y_n = marketable ear weight of the treatment receiving N input, Y_0 = marketable ear weight of the no-cover crop treatment without N input, and N_i = quantity of nitrogen input. The quantity of N input was either the amount of fertilizer N applied (174 kg/ha), the amount of N released from cover crop tissue between termination at planting and 9 weeks after planting (values are listed in Tab. II), or the sum of fertilizer N and released cover crop N. Nitrogen potentially released from cover crop root tissue was ignored since unpublished data that we obtained from another experiment on the same soil type as well as data of Sainju et al. (2005) showed that there is usually negligible N (10 kg/ha or less) in the roots of hairy vetch or a vetch-rye mixture.

3. RESULTS AND DISCUSSION

3.1. Sweet corn yield

Sweet corn marketable yield and yield components are presented in Tables III–V. Sweet corn weight per ha (fifth data

Table III. Sweet corn marketable yield components in 2003. Values followed by the same letter within columns are not significantly different ($P < 0.05$). There were no significant main effects for nitrogen and no significant interactions between cover crop and nitrogen for any variable in 2003 so only main effects of cover crop are shown.

Cover Crop	Plants (×1000/ha)	Ears per plant	Ears (×1000/ha)	Weight (g) per ear	Weight (Mg/ha)
None	43.4 a	0.88 b	37.5 a	273 a	10.1 a
Hairy vetch	39.1 ab	0.87 b	33.1 a	280 a	9.1 a
Hairy vetch + Rye	33.7 b	1.05 a	34.3 a	284 a	9.6 a

column) can be derived as the product of two components, ears per ha (third data column) and weight per ear (fourth data column). Also, sweet corn ears per ha can be derived as the product of two additional components, plants per ha (first data column) and ears per plant (second data column).

There were no differences among treatments in marketable sweet corn yield in 2003 (Tab. III). In 2004 and 2005, sweet corn marketable yield was highest in the no-cover crop treatment with fertilizer nitrogen but lowest in the no-cover crop treatment without fertilizer N (Tabs. IV and V). All yield components had a similar pattern of response to fertilizer N within the no-cover crop treatment as did ear weight per ha in 2004 and 2005. However, the component, ear number per ha, had a broader range of response (2 to 3 fold difference between the no-cover crop treatment with than without fertilizer N) than the component, weight per ear, and contributed most to determining ear weight per ha. Since population was similar among the no-cover crop treatments, the higher marketable ear number per plant was, therefore, the primary determinant of the increased ear number and weight per ha with than without fertilizer N.

Sweet corn yield was increased with the hairy vetch treatment compared to the no-cover crop treatment when no fertilizer N was applied but the reverse was true when fertilizer N was applied in 2004 and 2005 (Tabs. IV and V). This antagonism of sweet corn marketable yield by the hairy vetch treatment in the presence of fertilizer N is contrary to results obtained by others who have found no difference between a hairy vetch and a no-cover crop treatment when fertilized (Burgos and Talbert, 1996; Cline and Silvernail, 2002; Carrera et al., 2004). In 2004, the decrease in sweet corn yield in the fertilized hairy vetch treatment was driven by a non-significant 5% decrease in plants per ha and a non-significant 10% decrease in ears per plant that gave a significant 15% decrease in ear number per ha. In 2005, lower plant population was the main determinant of lower ear yield in the fertilized hairy vetch versus the fertilized no-cover crop treatment.

The hairy vetch-rye mixture reduced sweet corn plant population by 22% in 2003 (Tab. III) and by 57% in 2005 (Tab. V) compared to the no-cover crop treatment. High levels of the vetch-rye biomass were produced in all years (Tab. II) which created difficult planting conditions. Planting was performed into the standing cover crops followed by mowing or rolling operations in order to facilitate seed placement but the dense biomass and tough consistency of the rye crowns, in particular, still interfered with seed placement. Other researchers have also reported reduced sweet corn populations in a vetch-rye treatment (Burgos and Talbert, 1996; Cline and Silvernail, 2002; Carrera et al., 2004). Sweet corn compensated for reduced plants per ha in the vetch-rye treatment by producing more ears per plant in 2003 (Tab. III) and in the fertilized treatment in 2005 (Tab. V). This compensation was sufficient to offset the plant population effect in 2003 and resulted in no differences in yield per ha among cover crop treatments. However, in 2005, the increase in ears per plant was not sufficient to offset the high population reduction and yield per ha was lower in the vetch-rye treatment than either the no-cover crop or the hairy vetch treatment.

There were uniformly high yields in all treatments including the unfertilized no-cover crop treatment in 2003 suggesting that this field was high in fertility at the beginning of this experiment. However, because all treatments were kept on the same plots and all above-ground vegetation was removed as silage between years, sweet corn yield declined progressively in the unfertilized no-cover crop treatment in 2004 and 2005 (Tabs. III–V). Yield of all other treatments with some form of N input (fertilizer and/or vetch) remained relatively high across years, except for yields in the vetch+rye treatment in 2005 which declined because of a low crop population.

The analysis of cover crop management treatments revealed few significant differences between mowing and rolling. When there were differences, they were small and not consistent from year to year (data not shown). Therefore, all subsequent analyses were conducted ignoring this factor. Lack of significant differences between management treatments may be because decomposition of hairy vetch probably is driven more by internal cell collapse and deterioration of tissues than by whether the tissue is shredded by the mower or crimped by the roller. Choice of implements for flattening cover crop residue would best be determined by requirements other than those tested here, e.g. pest and weed management or economics.

3.2. Sweet corn biomass, N content, and efficiency of N use

Cover crops reduced early crop growth, both on an area and plant basis (Tab. VI).

The vetch-rye treatment reduced early growth more than the hairy vetch treatment in most instances. Cover crops produced abundant surface residue in all years (Tab. II) and surface residue is known to maintain cooler soil temperatures that can slow physiological processes (Fortin and Pierce, 1991). In addition, cover crops can produce allelopathic compounds

Table IV. Sweet corn marketable yield components in 2004. Values followed by the same letter within columns are not significantly different ($P < 0.05$).

Cover Crop	Fertilizer N (kg/ha)	Plants (×1000/ha)	Ears per plant	Ears (×1000/ha)	Weight (g) per ear	Weight (Mg/ha)
None	0	56.4 a	0.39 c	22.5 d	290 c	7.0 d
Hairy vetch		55.6 a	0.68 ab	37.5 bc	330 ab	12.7 bc
Hairy vetch + Rye		57.1 a	0.62 b	35.0 c	322 b	11.5 c
None	174	59.8 a	0.81 a	48.5 a	346 a	16.8 a
Hairy vetch		56.7 a	0.73 ab	41.1 bc	337 ab	14.0 b
Hairy vetch + Rye		55.2 a	0.75 a	41.2 b	336 ab	13.9 b

Table V. Sweet corn marketable yield components in 2005. Values followed by the same letter within columns are not significantly different ($P < 0.05$).

Cover Crop	Fertilizer N (kg/ha)	Plants (×1000/ha)	Ears per plant	Ears (×1000/ha)	Weight (g) per ear	Weight (Mg/ha)
None	0	53.7 a	0.22 c	12.2 d	261 c	3.2 e
Hairy vetch		47.1 b	0.55 b	25.7 b	285 bc	7.4 c
Hairy vetch + Rye		24.7 c	0.59 b	13.4 d	325 a	4.4 e
None	174	54.0 a	0.65 b	35.0 a	309 ab	10.8 a
Hairy vetch		46.0 b	0.62 b	28.5 b	303 ab	8.6 b
Hairy vetch + Rye		21.9 c	0.83 a	17.8 c	311 a	5.4 d

Table VI. Sweet corn plant biomass at 3 weeks after planting in 2003 and 2004 and 6 weeks after planting in 2005. There was insufficient biomass at 3 weeks after planting in 2005 to warrant a harvest. There were no significant interactions between cover crop and nitrogen for these variables so only the main effects of cover crop are shown. Values followed by the same letter within year are not significantly different ($P < 0.05$).

	Plant biomass (kg/ha)		
Cover Crop	2003	2004	2005
None	78.1 a	21.7 a	2461 a
Hairy vetch	59.2 ab	12.9 b	1821 b
Hairy vetch + Rye	40.0 b	10.2 c	536 c
	Weight (g) per plant		
None	1.68 a	0.37 a	45.6 a
Hairy vetch	1.47 a	0.23 b	39.0 b
Hairy vetch + Rye	1.11 a	0.18 c	22.5 c

Table VII. Sweet corn plant biomass and nitrogen content at 9 weeks after planting. Values followed by the same letter within year are not significantly different ($P < 0.05$).

Cover Crop	Fertilizer N (kg/ha)	2003	2004	2005
		Plant biomass (Mg/ha)		
None	0	8.08 b	8.86 a	6.37 bc
Hairy vetch		9.72 ab	10.63 a	8.29 a
Hairy vetch + Rye		10.74 ab	10.94 a	4.95 c
None	174	13.51 a	11.27 a	6.59 abc
Hairy vetch		9.47 b	11.08 a	7.94 ab
Hairy vetch + Rye		9.41 b	11.08 a	5.01 c
		Plant nitrogen content (%)		
None	0	2.38 ab	1.26 c	1.63 c
Hairy vetch		2.33 b	1.64 b	2.33 b
Hairy vetch + Rye		2.52 ab	1.42 bc	2.38 b
None	174	2.31 b	1.72 b	2.34 b
Hairy vetch		2.59 a	2.01 a	2.80 a
Hairy vetch + Rye		2.42 ab	2.15 a	2.95 a

which may contribute to suppression of early crop development (Fortin and Pierce, 1991; Dyck et al., 1995). Early crop biomass at 3 weeks after planting was not correlated with marketable yield in 2003 and 2004 (r = 0.16 and −0.04, respectively). However, crop biomass at 6 weeks after planting in 2005 (earliest sampling date in that year) was correlated with ear yield (r = 0.43), probably because the relation of early biomass to yield followed the same pattern as the relation of crop population to yield which appeared to be the primary determinant of yield loss (Tab. V).

There were few significant cover crop effects on sweet corn plant biomass at 9 weeks after planting (just after silking) and fertilizer N tended not to increase plant biomass within a given cover crop treatment (Tab. VII). Correlations between plant biomass at 9 weeks after planting and marketable yield were low in 2003 and 2004 (r = 0.30 and 0.36, respectively) but were higher in 2005 (r = 0.46). However, the correlation in 2005 was driven primarily by the correlation between biomass and yield within the vetch-rye treatment (r = 0.50) which was driven primarily by the correlation between population and yield within that treatment; within the no-cover crop treatment and the hairy vetch treatment, there was minimal correlation between biomass and yield (r = 0.15 and 0.24, respectively).

The N content of sweet corn plants at 9 weeks after planting tended to reflect the N inputs. The N content of plants with no N input was lowest in 2004 and 2005 (Tab. VII). The N content of plants with inputs of cover crop N, particularly the hairy vetch treatment, tended to be higher than that without cover crop. The N content of plants receiving fertilizer N was

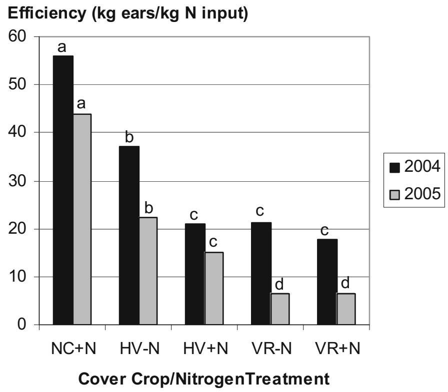

Figure 1. Efficiency of marketable sweet corn ear production per unit N input. Efficiency was computed as the difference between the yield of the specified treatment and the yield of the unfertilized no-cover crop control divided by the amount of nitrogen input from fertilizer and/or cover crop decomposition. Abbreviations: NC+N = no cover crop with fertilizer N, HV–N = hairy vetch without fertilizer N, HV+N = hairy vetch with fertilizer N, VR–N = hairy vetch-rye mixture without fertilizer N, VR+N = hairy vetch-rye mixture with fertilizer N. Bars with the same letters within year are not significantly different ($P < 0.05$).

higher than the corresponding cover crop treatment without fertilizer N. Plant N content was not correlated to marketable yield within the cover crop treatments but was highly correlated to yield within the no-cover crop treatment in 2004 and 2005 (r = 0.66 and 0.70, respectively).

The efficiency of yield per N input was not computed for 2003 because there were no significant differences in yield among treatments in that year, but was computed for 2004 and 2005 because there were significant differences between the yield of treatments with and without N inputs in those years. Marketable sweet corn yield was increased more efficiently by fertilizer N than by hairy vetch N (Fig. 1). Adding fertilizer N to the hairy vetch treatment decreased yield per N input efficiency compared to the hairy vetch treatment alone. Hairy vetch, alone, was more efficient than the vetch-rye treatment but the low efficiency of the vetch-rye treatment in 2005 was likely because of low population rather than N utilization.

Higher yield per N input efficiency with fertilizer N than with the hairy vetch in 2004 and 2005 was not related to greater N released into soil by fertilizer N. An estimated 80 to 84% of N was released from hairy vetch residue by 9 weeks after planting (Tab. II), providing a similar amount of N as the 174 kg/ha that was applied as fertilizer. Research using ^{15}N isotope has shown that corn uptake of N from fertilizer can be approximately double that taken up from hairy vetch or other legume residue (Harris et al., 1994; Kramer et al., 2002; Seo et al., 2006). In these ^{15}N studies, legume N tended to partition more into soil organic fractions (Harris et al., 1994; Seo et al., 2006), particularly into soil microbial biomass (Harris et al., 1994), than did fertilizer N. Decreased early growth of corn in cover crop treatments versus the no-cover crop treatment (Tab. VI) may be partially explained by slower release of N from residue and cooler soil conditions that would delay root access to and uptake of available N. But corn biomass and N content by 9 weeks after planting in the hairy vetch treatment were comparable or superior to the fertilized no-cover crop treatment (Tab. VII) indicating there was a sufficient supply of soil N to drive growth. Reduced marketable yield and yield per N input efficiency in the hairy vetch treatment versus the fertilized no-cover crop treatment is explained more by reduced corn populations (Tabs. IV and V) than by unavailability of or inability to uptake soil N. Adding fertilizer N to the hairy vetch treatment did little to compensate for this population effect on yield potential and resulted in lowering the yield per N input efficiency relative to the hairy vetch treatment without fertilizer N.

Our results and that of others (Ranells and Wagger, 1996; Sainju et al., 2005) show that hairy vetch and hairy vetch-rye cover crops can release N amounts similar to or greater than recommended fertilizer N rates (Tab. II). Estimates of the overall proportion of fertilizer N taken up by corn average about 50% (Karlen et al., 1998). Research accounting for the fate of fertilizer or cover crop ^{15}N in the soil-plant system found recoveries ranging from 50 to 85%, suggesting that 15 to 50% would be subject to loss into the environment (several studies summarized in Seo et al., 2006). Significant amounts of cover crop N have been shown to be lost to leaching or denitrification before uptake by corn or soil microbial biomass (Rosecrance et al., 2000). In light of the low efficiency of cover crop N use by corn, particularly with a combination of cover crops and fertilizer N (Fig. 1), potentially large quantities of N, therefore, could be lost into the environment following sweet corn harvest (Brandi-Dohrn et al., 1997). These results suggest that a different management approach is needed other than attempting to meet N requirements for sweet corn by maximizing cover crop biomass and N production.

4. CONCLUSION

In the short term, as measured over the three years of this experiment, sweet corn grown with fertilizer N without a cover crop resulted in the highest and most efficiently produced marketable yields. Sweet corn grown in high quantities of hairy vetch and vetch-rye residue, that released similar N levels to that of applied fertilizer N, increased sweet corn yield when no fertilizer was applied but antagonized yield in the presence of fertilizer N. Yield reductions by cover crops were attributed primarily to reduced sweet corn population, probably the result of interference with seed placement during planting into the abundant residue biomass. This research was conducted during three growing seasons with good rainfall; more droughty conditions could have favored the benefits of cover crop residue for improving infiltration (McVay et al., 1989) and conserving soil moisture (Clark et al., 1995). Regardless, our results demonstrate that planting directly without tillage into cover crop residue that has been allowed to produce high biomass and N content may not be an advisable practice.

In the long-term, no-tillage crop production using cover crops will provide long-term soil improvements in organic matter and related properties (Sainju et al., 2003) as well as provide soil protection during winter months. In order to avoid problems of planting into potentially heavy cover crop biomass levels, it may be desirable to kill cover crops earlier than planting. Research with field corn showed improved crop performance when hairy vetch was killed at least one week before corn planting (Teasdale and Shirley, 1998). In addition, planter innovations may be needed to reduce residue interference with no-tillage planting (Torbert et al., 2007). Following sweet corn harvest, use of an effective N capturing cover crop such as rye (Shipley et al., 1992) or forage radish (A. Kremen and R. Weil, U. of Maryland, personal communication, 2007) would alleviate potential losses of excess N remaining in soil. Future research should determine the optimum timing of cover crop kill relative to planting and the associated N dynamics to facilitate achieving the long-term benefits of cover crops while avoiding interference with crop production and excess N losses before and after harvest.

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