Published September 6, 2013

Apparent Red Clover Nitrogen Credit to Corn: Evaluating Cover Crop Introduction

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ABSTRACT

Corn (*Zea mays* L.) production systems can benefit from introducing a leguminous winter cover crop into the rotation, especially with regard to increased N availability (i.e., legume N credit); however, it is not known if the full agronomic benefit is realized in the first year of cover crop introduction or if the benefit is cumulative with time. The objective of this study was to determine the apparent red clover (*Trifolium pratense* L.) N credit to corn in a conventional system where red clover was introduced for the first time compared with three agricultural systems that had a 14-yr history of using cover crops. The apparent red clover N credit was calculated by the difference in unfertilized corn N accumulation between cover and no-cover split-split plots. These data suggest that corn growers can realize the full benefits of a red clover cover crop in the first year of introduction.

The value of using cover crops includes reduced soil erosion, gains in soil organic matter, capture of unused fertilizer N, decreased soil compaction, and suppression of diseases and weeds when compared with bare soil or winter fallow (Snapp et al., 2005; Tonitto et al., 2006; Cherr et al., 2006). Before industrial manufacturing of inorganic fertilizers, the most common reason for using a legume cover crop was to enhance soil fertility, especially N (Dinnes et al., 2002). Many studies have attributed the benefit of a legume cover crop before corn to an increase in soil N levels following legume incorporation (Hesterman et al., 1986; Blevins et al., 1990; Torbert et al., 1996; Vyn et al., 1999; Sanchez et al., 2001); however, other non-N rotational benefits have been identified as well (McVay et al., 1989; Raimbault and Vyn, 1991; Corak et al., 1991). In total, the direct contribution of N from legume N_2 fixation coupled with factors such as improved soil physical, chemical, and biological properties may synergistically produce the overall "rotational effect" (Gaudin et al., 2013); however, legume cover crops are generally managed as a N source (Tonitto et al., 2006; Liebman et al., 2012).

Red clover, when frost-seeded into winter wheat (*Triticum aestivum* L.), has been shown to fix and accumulate large amounts of N in the aboveground biomass and has been evaluated as a green manure prior to corn production (Hesterman et al., 1992; Tiffin and Hesterman, 1998; Schipanski and Drinkwater, 2011; Gaudin et al., 2013). Due to the low C/N ratio of red clover tissues, N turnover is generally faster than for nonleguminous cover crops (Varco et al., 1989; Wagger, 1989); however, environmental and management factors can markedly influence decomposition dynamics, and it is difficult to accurately predict the amount of N that will become available, or when it will become available, to a subsequent crop (Crews and Peoples, 2005; McSwiney et al., 2010; Ruffo and Bollero, 2003). Snapp et al. (2005) determined that uncertainty regarding N mineralization and availability was one of the chief barriers to adoption of legume cover crops among surveyed Michigan farmers. Determining the N credit value of a cover crop is critical for calculating the N fertilizer application rate that maximizes profit and protects the environment (Andraski and Bundy, 2002; Stute and Posner, 1995; Vyn et al., 1999). Knowledge is limited, however, concerning longer term, decadal interactions of producing cover crops within a given cropping system.

Long-term field crop experiments greatly improve our understanding of historical management effects on soil properties, including slow processes such as soil organic matter accumulation (Sanchez et al., 2004; Robertson et al., 2008). During the first decade of a row crop experiment in southwest Michigan, the presence of cover crops in a corn–soybean [*Glycine max* (L.) Merr.]–wheat rotation supported soil C increases of 10 to 40 g C m^{-2} annually (Robertson et al., 2000). Similarly, diversification with cover crops in a 14-yr organic corn–soybean–wheat rotation experiment in Pennsylvania enhanced soil C by 42 g C m^{-2} annually (Drinkwater et al., 1998). Although these studies demonstrate gains in soil C and improved soil fertility, the timing of nutrient release, particularly with regard to soil N supply, has been shown to be one of the primary yield-limiting factors for cash crop production in organic farming systems (Cavigelli et al., 2008).

Soil fertility amendments (i.e., fertilizers, composted dairy manure, and green manures) are generally applied to enhance the growth and yield of the cash crop. Although rarely studied, it can be inferred that practices improving soil nutrient and organic matter status will, in turn, enhance cover crop performance. We hypothesized that agricultural systems that have

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Published in Agron. J. 105:1658–1664 (2013)
doi:10.2134/agronj2013.0089

historically used cover crops may accumulate soil organic matter and therefore support greater cover crop productivity, producing larger rotational effects and cover crop N credits with time. The objective of this experiment was to determine the apparent red clover N credit to corn in a long-term crop rotation study where a cover crop (mammoth red clover) was introduced into the rotation for the first time compared with three agricultural systems that had a 14-yr history of using cover crops.

MATERIALS AND METHODS

Site Description

This study was conducted at the Living Field Laboratory (LFL) established in 1993 at the W.K. Kellogg Biological Station located in Kalamazoo County, Michigan. The area receives approximately 90 cm of precipitation annually, about half as snow. Precipitation was measured on site from 1988 to 2012. The site has a mixture of Kalamazoo and Oshtemo sandy loam soils (Typic Hapludalfs), with approximately 7250 and 680 mg kg^{-1} total C and N when the plots were established in 1993 (Sanchez et al., 2004).

Experimental Design

The overall goal of the LFL was to investigate the benefits of cover crop and composted dairy manure inputs on crop yield and environmental performance. Two integrated management systems (integrated fertilizer [IF] and integrated compost [IC]) were compared with a conventional system (CO) and an organic system (OR; formerly TO) (Sanchez et al., 2004). A split-split-plot experimental design with four replications was established to represent the management system (whole plot), phase of the crop rotation (split plot), and cover treatment (split-split plot) (Sanchez et al., 2004). From the initiation of the study in 1993, plots in the IF, IC, and OR systems were split with a winter cover crop or winter fallow. Cover crop and winter fallow split-split plots have been maintained on the same halves of each plot throughout this long-term experiment. Individual split plots were 9.1 by 20.0 m, accommodating 12 crop rows spaced 0.76 m apart for corn and soybean, whereas wheat was planted in 0.19 m rows. Split-split plots for cover crop or winter fallow consisted of six crop rows, where the middle two rows were harvested for yield determination. The CO system was not split for cover treatments until red clover was introduced as a green manure in the spring of 2006.

Historical Management (1993–2005)

The term *integrated* refers to targeted, banded application of herbicide to control weeds and stringent accounting of N inputs using the presidedress NO_3 test and N analysis of composted dairy manure. Herbicide was broadcast in the CO system, banded over the row in the IF and IC systems at one-third the rate of the CO system, and omitted from the OR system (Table 1). Herbicide application differences among the systems caused differences in tillage operations such that only the IF, IC, and OR systems received a row cultivation operation, while the OR system also received two rotary hoe operations.

The crop rotation was corn–corn–soybean–wheat, with every phase of the rotation present each year (Sanchez et al., 2004). Second-year corn was discontinued in 2003 and replaced with soybean to create a 3-yr rotation of corn–soybean–wheat. Cover crops used in the IF, IC, and OR systems varied according to the previous cash crop; red clover was frost-seeded into winter wheat residue preceding first-year corn, crimson clover (*Trifolium incarnatum* L.) was interseeded (after row cultivation) into the first-year corn preceding second-year corn, and annual ryegrass (*Lolium multiflorum* Lam.) was interseeded into the second-year corn preceding soybean. Winter fallow cover consisted of a combination of volunteer winter wheat, winter annual weeds, and immature summer annual weeds.

The N fertilizers used in this study were synthetic, inorganic N fertilizers in the CO and IF systems and composted dairy manure in the IC and OR systems (Table 1). Inorganic fertilizer N was applied to corn at planting as a starter liquid fertilizer and sidedressed as NH_4NO_3 according to yield goal calculations for the CO system and the presidedress NO_3 test for the IF system (Vitosh et al., 1995). Thus CO generally received more fertilizer N than IF. Wheat received a topdressing of urea in mid-March, while soybean received no fertilizer N. In the IC and OR systems, compost with C/N ratios ranging from 11:1 to 13:1 was applied annually at a rate of approximately 100 kg N ha^{-1} for first-year corn and 200 kg N ha^{-1} for second-year corn; no N fertilizer source was applied to soybean.

Soil Sampling

To assess soil P and K levels, a composite of three soil samples was taken from each split plot to a depth of 25 cm with a 1.9-cm-diameter soil probe on 20 Mar. 2006. Soil samples from each plot were mixed, sieved to <2 mm, and air dried. Analysis for available P (Bray P1) and K (Mehlich 3) were conducted at A&L Great Lakes Laboratories (Fort Wayne, IN). Soil test results were used to determine the P and K fertilizer applications required for corn production (Vitosh et al., 1995). On 2 Apr. 2008, a composite of eight cores per split-split plot were taken to a depth of 25 cm with a 1.9-cm-diameter soil probe. Samples were ground to a fine powder with a shatterbox mill 8515 (SPEX), and 20 mg of soil was packed into pressed tin capsules and analyzed for total C and N by dry combustion using a Costech C and N analyzer.

Cover Crop Management and Sampling

From 1993 to 2005, cover split-split plots in IF, IC, and OR were sown with red clover and crimson clover three times each and with annual ryegrass two times. This investigation coincided with the fourth time during this long-term experiment that the winter wheat–red clover phase of the crop rotation was sown. On 21 Mar. 2005, mammoth red clover was frost-seeded into wheat at a rate of 20 kg seed ha^{-1} in the IF, IC, and OR systems. On 1 May 2006, red clover and winter fallow biomass were randomly sampled by collecting all aboveground biomass in two 0.25-m^2 quadrats per split-split plot from all replicates. The aboveground biomass was dried to a constant weight at 65°C, weighed, ground to pass a 1-mm screen in a Christy-Turner 3.15-cm lab mill, and analyzed for C and N using dry combustion as described above. Immediately following biomass sampling, glyphosate [*N*-(phosphonomethyl) glycine] was broadcast applied at 0.5 kg ha^{-1} a.i. to the red clover and winter fallow split plots in the CO, IF, and IC systems. This operation marked the termination of banded herbicide applications in the IF and IC systems; from this point onward, all herbicide applications were broadcast in the CO, IF, and IC systems. On 5 May, red clover was flail mowed in the OR system.

On 20 Mar. 2006, mammoth red clover was frost-seeded into wheat at 20 kg seed ha^{-1} for all four management systems, which marked the introduction of red clover into the CO system. Again, this was the fourth time during the cropping sequence that red clover had been sown in the IF, IC, and OR systems; however, this was the first time any type of cover crop had been sown in the CO system. On 23 Apr. 2007, winter fallow split-split plots in the CO, IF, and IC management systems were sampled for biomass, and glyphosate was broadcast applied at 0.5 kg ha^{-1} a.i. On 4 May, red clover biomass in all four systems and winter fallow biomass in the OR system were sampled, and glyphosate was broadcast at 0.5 kg ha^{-1} a.i. in the CO, IF, and IC systems. On 8 May, red clover was flail mowed in the OR system.

Tillage

In 2006 and 2007, tillage practices for all corn plots were managed identically in all four systems, except that the OR system received a rotary hoe operation for early weed control. On 5 May 2006 and 8 May 2007, the red clover biomass was incorporated with a chisel plow in all four systems. Corn seedbed preparation was performed with a soil finisher/field cultivator on 23 May 2006 and 18 May 2007. A rotatory hoe was used in the OR system on 1 and 5 June in 2006 and on 24 May and 1 June in 2007. A row cultivator was used in all four systems on 28 June 2006 and 22 June 2007.

Corn Herbicide Application

A pre-emergence corn herbicide mixture of mesotrione (2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione) at 0.2 kg ha^{-1} a.i., *S*-metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(1*S*)-2-methoxy-1-methylethyl] acetamide) at 1.9 kg ha^{-1} a.i., and atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine) at 0.7 kg ha^{-1} a.i. was applied to corn on 26 May 2006 and 20 May 2007 in the CO, IF, and IC systems. To eliminate the effect of weed competition on plant N availability (especially in the OR system), however, corn plots in all four systems were hand weeded following row cultivation each year.

Corn Management and Sampling in 2006 and 2007

Composted dairy manure (12 Mg ha^{-1} with 0.87% N) was applied to the OR system on 29 April 2006 and 3 May 2007. We suspended application of composted dairy manure to the IC system in 2006 and 2007 to determine the effect of recent vs. historical applications on the red clover N credit. Inorganic fertilizer N was not applied to corn in 2006 and 2007 to investigate N uptake and grain yield as indicators of N availability from cover crops and management systems. Based on fertilizer recommendations for corn in this region (Vitosh et al., 1995), the CO and IF systems received P fertilizer in the form of triple superphosphate (0–45–0 N–P_2O_5–K_2O) at a rate of 50 kg P_2O_5 ha^{-1} and K fertilizer in the form of potassium chloride (0–0–63 N–P_2O_5–K_2O) at a rate 84 kg K_2O ha^{-1} on 29 Apr. 2006 and 2 May 2007. The IC and OR systems had sufficient levels of P and K and did not require additional amendments.

Pioneer corn hybrid 36W66 (103-d relative maturity rating) was planted at a population of 81,500 plants ha^{-1} on 25 May 2006 and 21 May 2007. At 32 d after planting, the plots were thinned to a stand of 69,160 plant ha^{-1}. Irrigation water was not applied to the experiment in 2006. To ensure corn pollination in 2007, however, we applied an average of 25 mm (±13 mm) of water across all plots with an irrigation gun (B.B. Hobbs) on 19 and 31 July. The groundwater used for irrigation contained 8.3 mg L^{-1} of NO_3–N, thus a total of approximately 4 kg N ha^{-1} was added to all systems via irrigation in 2007.

At physiological maturity, eight randomly selected plants were harvested from the two yield rows for biomass and N determination. Plants were separated into three fractions: leaves and stalks; husk, shank, tassel, and cob; and grain (Gentry et al., 1998). Plant fractions were dried to constant weight at 65°C for biomass determination and ground through a 1-mm mesh screen with a Christy mill. Plant fractions were analyzed for N in 2006 by colorimetric methods at A&L Great Lakes Laboratory and for C and N in 2007 using a Carlo-Erba NA 1500 CNS. A subset of plant samples from 2006 was reanalyzed in 2007, and results indicated that the two methods were in agreement.

Corn grain yield was determined by hand harvesting the center 5.3 m of each of two yield rows (including grain from the eight-plant sample). Stand counts were taken to determine final plant population. Grain was weighed fresh, and dry weight was determined using a DICKEY-john moisture meter. Overall, these four measurements (total aboveground corn biomass, biomass N, grain yield, and grain N concentration) indicated corn performance.

Calculations for Nitrogen Contribution from Red Clover and Apparent Nitrogen Credit to Corn

To estimate the contribution of N from red clover N_2 fixation, we calculated the net cover crop biomass N by determining the difference in aboveground biomass N between the red clover and winter fallow split-split plots for each management system. We considered aboveground N accumulation of unfertilized corn as an estimate of net soil N mineralization (Gentry et al., 2001). By determining the difference in corn aboveground biomass N accumulation between the cover crop and winter fallow split-split plots, we estimated the apparent N credit of red clover to corn for each system. The apparent N credit values are conservative when compared with bare soil systems (i.e., fall tillage or herbicide application) but accurately represent N cycling in fields with modest weed presence during the winter fallow period.

Data Analysis

Treatment effects of cultural management (cropping system) and cover crop were evaluated for soil properties (i.e., soil C and N), cover (red clover vs. winter fallow) biomass and biomass N, corn biomass and biomass N, corn grain yield, and grain N concentration. System effects were also evaluated for the net N contribution of cover crop biomass and apparent N credit to corn as a result of cover crop establishment. Analysis of variance was conducted using a generalized linear mixed model; system and cover treatments and year were declared fixed effects and replication was declared random. All data analyses were conducted with SAS, version 9.2, of the SAS System for Windows (SAS Institute). Significant effects were further investigated with a test of least significant difference (LSD) at $P = 0.05$ for main effect means and interactions. Normality of residuals was tested using the Shapiro–Wilk test. Cover crop biomass N data were square-root-transformed before statistical analysis to meet the requirements of normality.

RESULTS AND DISCUSSION

Weather

The 24-yr (1988–2012) average annual precipitation for this research site was 890 mm. Total precipitation was above average in 2006 (1150 mm) and below average in 2007 (852 mm). During June of both years, precipitation was below average; however, timely rainfall in July of 2006 reversed crop moisture stress (Fig. 1). In 2007, rainfall in July was only 19 mm, which created severe drought stress conditions. As described above, irrigation water was applied twice in July 2007 to ensure corn pollination. Irrigation sustained the crop, and precipitation events in early August ended the drought and plant growth quickly responded (i.e., chlorophyll content quickly increased; data not shown). Rainfall was above average in August during corn grain fill for both years.

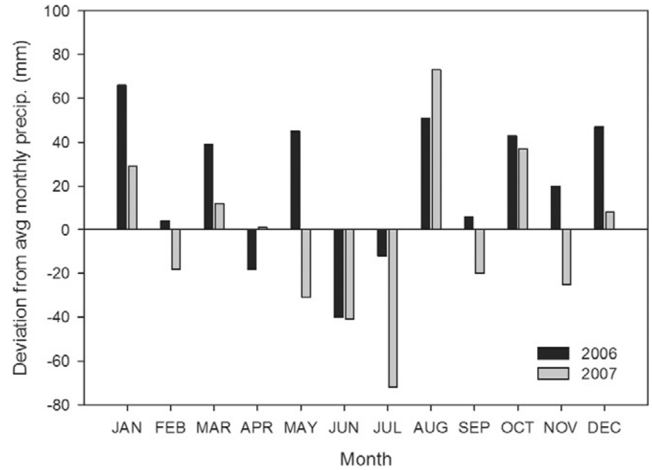

Fig. 1. Monthly departures from 24-yr precipitation average (1988–2012) for 2006 and 2007 at the site of a long-term crop rotation experiment located at the W.K. Kellogg Biological Station, southwest Michigan.

Soil Carbon and Nitrogen

Soil C and N concentrations were determined from samples taken in spring 2008, following the last growing season of the reported study. Results demonstrate a strong cultural management effect ($P < 0.0001$ for both soil C and N). Cover treatment did not affect soil C ($P = 0.7801$) or soil N ($P = 0.5237$), and there were no significant interactions.

Soil C ranged from 7234 to 12944 mg kg^{-1} and soil N ranged from 761 to 1156 mg kg^{-1} for the CO system compared with the OR system (Table 1). Gains in soil C followed a management gradient from low to high organic inputs: 27% higher soil C in IF, 61% higher in IC, and 79% higher in OR relative to CO. Soil N concentrations followed a similar pattern, 20% higher soil N in IF, 39% higher in IC, and 52% higher in OR relative to CO (Table 1). Sanchez et al. (2004) reported soil C values for this experiment from 1993 to 2000, indicating that the systems had significantly diverged with regard to total C as early as 1996. By 2000, management had significantly impacted total C accumulation, with the CO system remaining unchanged and the OR system showing gains of 3000 mg C kg^{-1}. They concluded that compost additions and the level of weed control (i.e., system differences for weed biomass production) had a strong influence on total soil C and N.

Effect of Management and Cover Crop Treatment on Corn Performance

Analysis of variance of management systems (IF, IC, and OR in 2006; CO, IF, IC, and OR in 2007) and cover (red clover vs. winter fallow) demonstrated that cover biomass and cover biomass N as well as four measurements of corn performance (biomass, biomass N, grain yield, and grain N) were strongly affected by both system and cover (Table 2). There were no interactions between system and cover for any measurements. There was a significant year effect and/or significant year interaction(s) for most measurements.

Evaluated across systems, red clover produced significantly greater aboveground biomass and biomass N than winter fallow in both 2006 and 2007 (Table 3). Red clover biomass values reported here are similar to other studies using interseeded red clover in winter wheat with spring cover crop termination (Dapaah and Vyn, 1998; Vyn et al., 1999, 2000; Queen et al., 2009). Red clover biomass production was similar between years; however, biomass N was greater in 2007 than in 2006. Red clover biomass N concentration was approximately 0.5% greater in 2007 than in 2006 (data not shown).

Numerous studies have documented the production benefits of a legume cover crop sown before corn production (Hesterman et al., 1986; Vyn et al., 1999; Kuo and Jellum, 2000; Schipanski and Drinkwater, 2011). In this study, all corn performance measurements were significantly increased by red clover compared with winter fallow except for grain yield in 2007 (Table 3). Although corn biomass and corn biomass N following red clover in 2007 increased by 17 and 38% compared with corn following winter fallow, grain yield was not significantly greater. Dry conditions during early crop development in 2007 produced relatively small corn plants that accumulated the majority of their N during grain fill, creating relatively large yields and harvest indices as great as 60% (data not shown).

Grain N concentration increased by 14% for corn following red clover compared with winter fallow in both years (Table 3). Although grain yields for corn following red clover were similar between years, grain N concentrations were 39% greater in 2007 than in 2006, which accounted for most of the overall difference in aboveground corn biomass N accumulation between years. The overall greater corn biomass N accumulation for both cover treatments in 2007 suggests that net soil N mineralization was significantly greater during the 2007 growing season (Gentry et al., 2001). We speculate that ample rainfall in August of 2007 following the extremely dry month of July produced a flush of soil N mineralization across all management systems and cover treatments (Birch, 1958; Franzluebbers et al., 2000; Mikha et al., 2005). This apparent "Birch effect" occurred approximately 1 wk after corn pollination, coinciding with a period of rapid uptake and partitioning of N to the developing corn grain (Bender et al.,

Table 1. Systems description of historical management (1993–2005): weed control, N fertility source and rate (by crop), and soil C and N content (2008) for four systems—conventional (CO), integrated fertilizer (IF), integrated compost (IC), and organic (OR)—in a long-term crop rotation experiment located at the W.K. Kellogg Biological Station, southwest Michigan.

		Range of annual inorganic fertilizer N†			Annual amount of total N in compost				
System	Weed control	Corn	Soybean	Wheat	Corn‡	Soybean	Wheat	Soil C	Soil N
		kg N ha^{-1}						mg kg^{-1}	
CO	broadcast herbicide	90–188	0	62–90	0	0	0	7234 d§	761 d
IF	banded herbicide + row cultivator	67–161	0	62–90	0	0	0	9187 c	915 c
IC	banded herbicide + row cultivator	0	0	0	100	–	100	11622 b	1057 b
OR	rotary hoe + row cultivator	0	0	0	100	–	100	12944 a	1156 a

† Fertilizer application rate based on presidedress N test results.
‡ Compost application was double the rate in second-year corn.
§ Average values for soil measurements followed by the same letter are not significantly different ($P < 0.05$).

Table 2. Sources of variation and corresponding *P* values among systems (integrated fertilizer, integrated compost, and organic in 2006; the same plus conventional in 2007), cover (red clover vs. winter fallow), and year (2006 and 2007) for cover biomass, cover biomass N, corn biomass, corn biomass N, corn grain yield, and corn grain N. Data are from a long-term field crop experiment at the Kellogg Biological Station in southwest Michigan.

	P > F					
Source of variation	Cover biomass	Cover biomass N	Corn biomass	Corn biomass N	Corn grain yield	Corn grain N
System	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cover	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
System × cover	0.3850	0.4288	0.8699	0.6885	0.9647	0.1960
Year	0.0538	0.9015	0.0882	<0.0001	0.0023	<0.0001
System × year	0.0903	0.0490	0.3989	0.0362	0.1330	0.0096
Cover × year	0.3597	0.0007	0.3220	0.0441	0.0070	0.8808
System × cover × year	0.8916	0.8166	0.9487	0.4808	0.6905	<0.0001

Table 3. Average values for cover and corn grain measurements as affected by cover treatment (red clover or winter fallow) averaged across system treatments for 2006 and 2007 in a long-term field experiment at the Kellogg Biological Station in southwest Michigan.

Year	Cover	Cover biomass	Cover biomass N	Corn biomass	Corn biomass N	Corn grain yield	Corn grain N
		Mg ha^{-1}	kg N ha^{-1}	Mg ha^{-1}	kg N ha^{-1}	Mg ha^{-1}	%
2006	red clover	2.21 a†	80.73 b	14.24 a	121.65 b	7.20 a	1.10 c
	winter fallow	1.17 b	31.21 c	11.77 b	91.91 c	5.16 b	0.96 d
2007	red clover	2.07 a	92.64 a	13.11 a	174.48 a	7.19 a	1.53 a
	winter fallow	0.76 c	20.13 c	11.20 b	126.26 b	6.39 a	1.34 b

† Average values followed by the same letter are not significantly different ($P < 0.05$).

2013). Although the yield response to red clover may have been restricted by drought in 2007, the uptake of N during grain fill greatly enhanced grain quality.

To evaluate the historical effect of cultural management, the six study variables were averaged across cover treatments (Table 4). Similar to soil C and N results, increases in cover biomass and biomass N followed the management gradient of low to high organic inputs, with cover biomass and biomass N significantly lower in IF than OR. Historical management also affected corn performance because all four measurements were significantly greater in the two compost systems (IC and OR) than in the inorganic fertilizer systems (IF in 2006, CO and IF in 2007). Suspending the compost addition before corn production in the IC system did not significantly affect corn performance measurements (IC vs. OR); however, the legacy effects of long-term compost additions significantly enhanced corn performance (IC vs. IF).

The CO system was added to the analyses in 2007 when red clover and winter fallow split-split plots were introduced for the first time since the experiment was initiated. There were no significant differences between the CO and IF systems for any of the six study variables, further indicating that these systems were managed identically in 2007 (Table 4). These data indicate that there were no differences in corn performance measurements between the CO and IF systems despite management legacy effects (i.e., increased soil C and N due to greater historical weed biomass production in IF).

Apparent Red Clover Nitrogen Credit

There were no significant differences among management systems for either net cover biomass N (red clover biomass N minus winter fallow biomass N) or apparent red clover N credit (corn biomass N following red clover minus corn biomass N following winter fallow) (Table 5). Values for both calculations significantly differed between years ($P < 0.05$). The system ′ year interaction was nonsignificant for both net cover biomass N and apparent N credit.

Values for net cover biomass N were statistically similar across management systems in a given year because both red clover and winter fallow biomass N tended to increase in

Table 4. Average values for corn grain yield measurements among conventional (CO; 2007 only), integrated fertilizer (IF), integrated compost (IC), and organic (OR) systems, averaged across cover treatments for 2006 and 2007 in a long-term field experiment at the Kellogg Biological Station in southwest Michigan.

Year	System	Cover biomass	Cover biomass N	Corn biomass	Corn biomass N	Corn grain yield	Corn grain N
		Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg N ha^{-1}	Mg ha^{-1}	%
2006	IF	1.40 b†	45.92 c	11.32 c	87.79 c	5.04 c	0.97 d
	IC	1.86 a	60.66 b	13.87 a	114.40 b	6.71 ab	1.02 cd
	OR	1.81 a	61.34 ab	13.84 a	118.11 b	6.81 ab	1.10 c
2007	CO	1.20 b	45.17 c	11.14 c	123.41 b	6.40 b	1.30 b
	IF	1.22 b	50.14 c	11.16 c	126.25 b	6.43 b	1.34 b
	IC	1.36 b	54.51 bc	12.79 b	170.31 a	7.07 ab	1.54 a
	OR	1.88 a	75.73 a	13.53 ab	181.52 a	7.27 a	1.56 a

† Average values followed by the same letter are not significantly different ($P < 0.05$).

Table 5. Sources of variation among systems (conventional, integrated fertilizer, integrated compost, and organic) and years (2006 and 2007) for the net cover biomass N and apparent red clover N credit.

Source of variation	*P > F*	
	Net cover biomass N	Apparent N credit
System	0.9407	0.6712
Year	0.0016	0.0463
System × year	0.9590	0.4708

systems containing greater levels of soil C and N (Tables 1 and 6). Values for the apparent red clover N credit were also statistically similar across management systems in a given year (Table 6). It is interesting to note that historical or recent compost additions (IC vs. OR) did not significantly affect the apparent red clover N credit. Averaged across systems, red clover biomass production did not differ between years (Table 3); however, net cover biomass N and the apparent red clover N credit were significantly greater in 2007 than in 2006. For the IF, IC, and OR systems, the apparent N credit ranged from 20 to 35 kg N ha^{-1} in 2006 and 40 to 50 kg N ha^{-1} in 2007. These values are generally lower than reported in various university extension documents (Clark, 2007, p. 159–164; Stute and Shelley, 2009).

In the first year of cover crop introduction into the CO system, red clover imparted an apparent N credit of 55 kg N ha^{-1} in 2007, which represented the high end of the range of apparent N credit values determined for that year (Table 6). Legume residues have a low C/N ratio and are rapidly decomposed, providing readily available N to the subsequent crop (Bolger et al., 2003; Miguez and Bollero, 2005); however, legume N release may not be synchronous with the N requirements of the subsequent cash crop, thereby decreasing the recovery of legume N (Crews and Peoples, 2005). By dividing the average apparent N credit across systems by the average net cover biomass N across systems, we calculated the recovery of legume N by corn of 60 and 65% in 2006 and 2007. Although this suggests that 35 to 40% of the legume N remained in the system, there is no evidence in this study that long-term cover cropping has increased soil total N. Although microbial biomass may temporarily immobilize legume N, the lack of increase in soil C and N with time in these sandy loams may suggest that legume N has been lost from the system via NO_3 leaching.

Table 6. Average values for cover biomass N, corn biomass N, net cover biomass N, and apparent N credit for conventional (CO), integrated fertilizer (IF), integrated compost (IC), and organic (OR) cropping systems for 2006 and 2007 in a long-term field experiment at the Kellogg Biological Station in southwest Michigan.

Year	System	Cover	Cover biomass N	Corn biomass N	Net cover biomass N	Apparent N credit
			kg N ha^{-1}			
2006	IF	red clover	70.91	97.82	49.99 bc†	20.04 b
		winter fallow	20.92	77.78		
	IC	red clover	85.63	131.96	49.95 bc	35.05 ab
		winter fallow	35.68	96.91		
	OR	red clover	85.66	135.18	48.64 c	34.13 ab
		winter fallow	37.02	101.05		
2007	CO	red clover	79.27	151.05	68.16 abc	55.27 a
		winter fallow	11.11	95.78		
	IF	red clover	86.32	150.50	72.36 abc	48.51 a
		winter fallow	13.96	101.99		
	IC	red clover	91.43	195.06	73.84 ab	49.51 a
		winter fallow	17.59	145.55		
	OR	red clover	113.58	201.35	75.70 a	39.65 ab
		winter fallow	37.88	161.70		

† Average values followed by the same letter are not significantly different ($P < 0.05$).

CONCLUSION

A unique finding of this study was that growers can realize the full agronomic benefit (i.e., N fertility) of interseeded red clover to corn in the first year of cover crop introduction. Averaged across systems, the apparent red clover N credit was 30 and 48 kg N ha^{-1} in 2006 and 2007. Red clover sown before corn increased the corn aboveground biomass N accumulation by 32 and 38% in 2006 and 2007; however, corn grain yield was significantly greater only in 2006. We did not detect a legacy effect of historical cover cropping on soil C and N, nor was there a cumulative effect of long-term cover cropping on the apparent red clover N credit.

ACKNOWLEDGMENTS

We acknowledge Claire McSwiney and Briana Shuford for field assistance and Jennifer Gale for laboratory support. Support for this research was provided by the NSF Long-Term Ecological Research Program at the Kellogg Biological Station.

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