No-till and cover crop impacts on soil carbon and associated properties on Pennsylvania dairy farms

C.J. Dell, P.R. Salon, C.D. Franks, E.C. Benham, and Y. Plowden

Abstract: No-till (NT) crop production is expected to sequester soil C, but little data is available for dairy forage systems. Our objective was to quantify impacts of NT and rye (Secale cereale L.) cover crops on soil C and N pools and associated soil properties on Pennsylvania dairies. Samples were collected from seven fields following corn harvest. The NT fields had approximately 50% more C and N in particulate and mineral-associated pools in the upper 5 cm (2 in) compared to conventional tillage, but C and N accumulations below 5 cm were similar. This suggests a C sequestration rate of ~0.5 Mg ha⁻¹ yr⁻¹ (~0.2 tn ac⁻¹ yr⁻¹) in the 8 to 13 years NT has been used. Soil aggregate stability and cation exchange capacity were proportional to C pool sizes. Rye cover crops had no clear impact. Findings show that expected increases in C sequestration and soil quality with NT can be achieved in dairy forage systems.

Key words: carbon sequestration—cover crops—dairy forage—no-till

No-till (NT) planting, use of cover crops (CC), and other conservation practices are advocated to minimize soil erosion. These practices can also help mitigate climate change and improve soil quality. Reducing or eliminating tillage can slow the decomposition rate of plant residues and is generally expected to result in greater soil organic matter (SOM) accumulations. Carbon, which is incorporated into plant material during photosynthesis, is the primary component of SOM. Therefore, increasing SOM accumulations reduces the quantity of C returned to the atmosphere as CO₂, lessening the greenhouse effect. Additionally, increasing SOM can improve soil quality by enhancing key physical, chemical, and biological properties (Lal 2002).

Much of the suitable cropland in Pennsylvania and other northeastern US states is used to produce forages fed to dairy cattle. Crop rotations with four or more years of alfalfa followed by three to four years of corn are frequently grown. The majority of the corn is harvested for silage; therefore little corn residue is returned to the soil. Sloping topography and limited residue cover makes the use of NT planting and/or winter CC desirable to minimize soil erosion.

Numerous plot studies have shown that the use of NT planting has the potential to significantly increase soil organic C (SOC) accumulations near the soil surface (Blevins et al. 1983; Collins et al. 2000; Dick et al. 1997; Halvorson et al. 2002; Karlen et al. 1994; Lal et al. 1998; Olson et al. 2005). For example, Dick et al. (1997) reported that NT planting of grain corn for over 30 years at two sites in northern Ohio caused the total SOC in the upper 5 cm (2 in) to approximately double compared to the use of moldboard plowing and secondary tillage. However, little information is available on the impact of conservation practices on SOC accumulations in dairy forage production systems. Staley and Boyer (1997) reported greater SOC in the upper 7.5 cm (3 in) with NT, compared to plowing, when silage corn was grown for four years at a site in West Virginia that had been maintained as a low-input pasture for the prior 15 years. The authors attributed most of the difference in SOC between the tilled and NT plots to the loss of C immediately following the initial plowing of the pasture. Adoption of NT for silage corn production at a Tennessee site resulted in a 34% increase in SOC in the upper 15 cm (6 in) of soil over a 3-year period (Tolbert et al. 2002). Hooker et al. (2005) reported that 28 years of NT corn production significantly increased SOC, both with and without stover removal. The combined use of NT and CC (hairy vetch, Vicia villosa) in Georgia maintained SOC concentrations, while the use of NT alone or chisel and moldboard plowing systems (with and without CC) resulted in a statistically significant losses of SOC through three years of tomatoes and two years of silage corn (Sainju et al. 2002).

The additional plant residues contributed when CC are used provides the potential to increase SOC, but research findings have varied with factors such as CC species and soil fertility levels. Recent studies have shown a positive impact on SOC from CC containing legumes (Amado et al. 2006; Sainju et al. 2005; Sainju et al. 2006; Villamil et al. 2006), but reports of increases in SOC when cereal rye (Secale cereale) or oats (Avena sativa) is the winter CC are few. Ding et al. (2006) observed a small, but statistically significant, increase in SOC when a cereal rye was planted between corn (Zea mays L.) crops under high soil fertility, but showed no change when fertility was low. Use of cereal rye CC for five years in a NT corn/soybean (Glycine max [L.] Merr.) rotation in Illinois had no measurable effect on SOC, while the use of vetch or a mixture of vetch and rye significantly increased SOC (Villamil et al. 2006). Liu et al. (2005) measured a significant increase in SOC concentration after one winter (November 24 to April 14) when annual ryegrass (Lolium multiflorum) was used as a CC, but the use of cereal rye or barley (Hordeum vulgare) resulted in no detectable change in SOC over the same period.

While increases in SOC and associated soil properties are anticipated with the conversion to NT crop production, reported responses

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have varied among management systems and soil types and have not been validated extensively on commercial fields. Harvesting corn silage and alfalfa hay leaves little crop residue to be returned to the soil and may limit C sequestration. However, the planting of CC provides an additional C input and may increase SOC sequestration. This study presents the finding of an on-farm survey on central Pennsylvania dairy farms. Our objective was to evaluate the impact of NT silage corn production and fall-planted cereal rye CC on SOC and N accumulations and associated soil properties.

**Materials and Methods**

**Field Sampling.** Sampling occurred in November of 2003 and 2004 on dairy farms within the Nittany Valley in Clinton, Centre, and Huntingdon Counties, Pennsylvania. The region lies within the Appalachian Ridge and Valley Province and has mean annual temperature and rainfall of 9.2°C (49°F) and 97.5 cm (38.4 in). All sites were maintained in silage corn–alfalfa rotations, and soil sampling occurred following corn crops. Since corn was harvested for silage in September or October, little crop residue was returned to the field. Farms had similar corn silage yield goals (56 to 67 Mg ha⁻¹ [25 to 30 tn ac⁻¹]), and each field received dairy manure in years that corn was planted at rates that provided the crops’ N requirements. Dry, bedded-pack dairy manure was applied to fields 2 and 7, while the other fields received liquid dairy slurry. Manure analysis data were not available from the farms, therefore some variation in C and nutrient additions must be assumed among farms and with time for individual fields. Typical bedded pack manure from Pennsylvania dairies has about 30% dry matter that contains 1.8% to 2.5% total N and 0.4% to 0.7% total P. Dry matter content of dairy slurry varies with storage procedures, ranging from 5% to 20%. Slurry dry matter typically has 2.5% to 5.0% total N and 0.4% to 1.0% total P (Kleinman et al. 2005). Carbon content is not determined during routine manure analysis, but C generally comprises about 40% of the dry matter in dairy slurry and bedded-pack manure (Dell unpublished). Tillage and cereal rye CC usage differed among fields. Management details for each field are listed in table 1. Fields 4 and 5 are on the same farm, but other fields are on separate farms. With the exception of field 7, all soil samples were obtained from positions mapped as the Hagerstown series (Fine, mixed semiactive, mesic Typic Hapludalf). Sampling points in field 7 were mapped as the Hublersburg series (Clayey, illitic, mesic Typic Hapludult). Both the Hagerstown and Hublersburg soils are well drained and are derived from hard limestone. The primary distinction between the two series is a greater rock fragment concentration and lower cation exchange capacity (CEC) and percent base saturation in the Hublersburg series. The soil series designations were confirmed by USDA Natural Resources Conservation Service (NRCS) soil classification staff following detailed pit descriptions at each site.

For each field and sampling date, soil samples were obtained at three depths within three pits dug about 10 to 20 m (33 to 66 ft) apart in relatively flat sections of the fields. Soil was obtained from the 0 to 5 cm and 5 to 10 cm (0 to 2 in and 2 to 4 in) depths of the Ap horizon and from a 5-cm (2-in) thick layer of the upper Bt horizon (approximately 5 cm below the transition from the Ap horizon and 25 to 40 cm (10 to 16 in) below the surface). Three intact soil clods and approximately 5 kg (13 lb) of loose soil were collected from the faces of pits at each depth. Samples were shipped to the USDA NRCS National Soil Survey Center in Lincoln, Nebraska, for analysis. Locations of sampling pits were recorded with reference to distance from permanent landmarks in 2003.

**Soil Analysis.** Bulk soil samples were air-dried and used for the determination of particulate organic matter (POM) and mineral-associated (MIN) C and N, root biomass, particle size distribution, wet aggregate stability, pH, and CEC following protocols described in the USDA NRCS’s Soil Survey Laboratory Methods Manual (SSLMM) (Burt 2004). To separate POM and MIN fractions (SSLMM 6A4), a subsample of dried, sieved soil (<2 mm [0.08 in]) was shaken in deionized water with sodium hexametaphosphate, and passed through a 53-μm (0.002-in) sieve. The greater and less than 53 μm (0.002 in) soil fractions (POM and MIN, respectively) were then oven dried. Soils were finely ground, and C and N concentrations were then determined by combustion in an Elemental elemental analyzer (Elementar America, Mount Laurel, New Jersey).

An automated root washer was used to isolate roots for biomass determination (SSLMM 6C1). Roots were collected on a 0.5 mm (0.02 in) screen during washing. Material collected on the screen was air-dried, then transferred to a tray of water where organic material was floated off. Any roots that remained with the sand and gravel were removed by hand. After determination of the mass of recovered roots, subsamples of roots were ground and C and N were analyzed as described for soils.

Soil pH was determined using a 1:1 ratio of sieved (<2 mm [0.08 in]) air-dried soil and deionized water (SSLMM 4Ca2a1). Cation exchange capacity was determined by saturation of exchange sites with NH₄⁺ (applied as 1N NH₄Oac, pH 7) followed by extraction of NH₄⁺ with 2M KCl and measurement of NH₄⁺ by steam distillation and titration (SSLMM 4B4C1). The stability of soil aggregates from 0.5 to 1 mm (0.02 to 0.04 in) was determined using a wet sieving procedure (SSLMM 3F1). Crushed, air-dried soil was passed through 1 and 2 mm sieves (0.04 and 0.08 in). The material collected on the 1 mm (0.04 in) sieve was then transferred to a 0.5 mm (0.02 in) sieve and soaked in a pan of water overnight. After soaking, the sieve was raised and lowered in the water 40 times in 20 s. The mass of soil remaining on the 0.5 mm sieve was determined and the percent of soil remaining in stable aggregates (0.5 to 1 mm) calculated with a correction for the proportion of the initial soil mass accounted for by sand.

Particle size distribution (<2 mm [0.08 in]) was determined using the pipette method following treatment of sieved soil with hydrogen peroxide for removal of organic matter, the addition of sodium hexametaphosphate to disperse clays, and wet sieving to isolate sand (>53 μm [0.002 in]) (SSLMM 3A1a).

Intact soil clods were used to determine soil bulk density (Db) (SSLMM 3B1b) and water retention at field capacity (SSLMM 3C1c). Clods were coated in saran at the field site. In the lab, a flat surface was cut on clods and they were placed on a tension table. After the water content was equilibrated at 5-cm (2 in) tension, clods were transferred to a pressure plate where moisture was brought to field capacity (~33 kPa or ~0.33 bar), and moist mass was determined. Clods were re-coated with saran, and their volume was determined by water displacement. Saran was then removed by heating clods, the soil was sieved through a 2-mm (0.08-in) sieve, and the dry mass of the soil determined.
Table 1
Description of management practices and soil characteristics.

<table>
<thead>
<tr>
<th>Field</th>
<th>Location</th>
<th>Tillage*</th>
<th>Cover crop*</th>
<th>Most recent year in alfalfa</th>
<th>Soil series</th>
<th>Sampling Depth (cm)</th>
<th>Horizon</th>
<th>Texture†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41°02' N</td>
<td>No-till</td>
<td>Yes</td>
<td>1998</td>
<td>Hagerstown</td>
<td>0 to 5</td>
<td>Ap</td>
<td>SiCL</td>
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<tr>
<td></td>
<td>77°32' W</td>
<td></td>
<td></td>
<td>(1990)</td>
<td></td>
<td>5 to 10</td>
<td>Ap</td>
<td>SiCL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1990)</td>
<td></td>
<td>30 to 35</td>
<td>Bt</td>
<td>SiC</td>
</tr>
<tr>
<td>2</td>
<td>40°59' N</td>
<td>Chisel/disk</td>
<td>No</td>
<td>2002</td>
<td>Hagerstown</td>
<td>0 to 5</td>
<td>Ap</td>
<td>L</td>
</tr>
<tr>
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<td>77°35' W</td>
<td></td>
<td></td>
<td>(1990)</td>
<td></td>
<td>5 to 10</td>
<td>Ap</td>
<td>L</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1990)</td>
<td></td>
<td>36 to 41</td>
<td>Bt</td>
<td>L</td>
</tr>
<tr>
<td>3</td>
<td>40°56' N</td>
<td>Plow/disk</td>
<td>No</td>
<td>2000</td>
<td>Hagerstown</td>
<td>0 to 5</td>
<td>Ap</td>
<td>SiCL</td>
</tr>
<tr>
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<td>5 to 10</td>
<td>Ap</td>
<td>SiCL</td>
</tr>
<tr>
<td></td>
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<td>Bt</td>
<td>SiC</td>
</tr>
<tr>
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<td>No-till</td>
<td>No</td>
<td>2002</td>
<td>Hagerstown</td>
<td>0 to 5</td>
<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>(1991)</td>
<td></td>
<td>5 to 10</td>
<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1991)</td>
<td></td>
<td>30 to 35</td>
<td>Bt</td>
<td>SiCL</td>
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<tr>
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<td>(1991)</td>
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<td>SiL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1991)</td>
<td></td>
<td>30 to 35</td>
<td>Bt</td>
<td>SiC</td>
</tr>
<tr>
<td>6</td>
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<td>Hagerstown</td>
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<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
<td></td>
<td>77°56' W</td>
<td></td>
<td></td>
<td>(1998)</td>
<td></td>
<td>5 to 10</td>
<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1998)</td>
<td></td>
<td>23 to 28</td>
<td>Bt</td>
<td>SiL</td>
</tr>
<tr>
<td>7</td>
<td>40°37' N</td>
<td>No-till</td>
<td>Yes</td>
<td>1999</td>
<td>Hublersburg</td>
<td>0 to 5</td>
<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
<td></td>
<td>78°09' W</td>
<td></td>
<td></td>
<td>(1995)</td>
<td></td>
<td>5 to 10</td>
<td>Ap</td>
<td>SiL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1995)</td>
<td></td>
<td>46 to 51</td>
<td>Bt</td>
<td>SiCL</td>
</tr>
</tbody>
</table>

* Numbers in parentheses represent the year the practice was initiated.
† L = loam, SiC = silty clay, SiCL = silty clay loam, SiL = silt loam.

Density was then calculated using a correction for the coarse fragments (>2 mm) in the clods, and Db values were used to express soil C and N accumulations on an area basis. Water content at wilting point (-1,500 kPa or -15 bar) was determined from <2 mm soil samples that were placed on pressure plates, saturated, then equilibrated at -1,500 kPa (-15 bar). Plant-available water capacity was calculated from the difference in water retention capacity of the soil between field capacity and the permanent wilting point.

**Statistical analysis.** SAS PROC TTEST and the LSMEANS option of PROC GLM were used to test for significant differences between sampling years for each field and differences among fields (SAS version 8.2, SAS Institute, Cary, North Carolina). Because fields were sampled on separate farms and there was some variation in management factors, differences were considered significant at $p \leq 0.10$. T-tests indicated that no measured quantities differed between years in any field, so data from the two years were combined for comparisons among fields.

**Results and Discussion**

**Tillage related trends.** Differences in C and N pools among fields were observed in the upper 5 cm (2 in) of the Ap horizons (figure 1). No-till fields had, on average, 51% more MIN-C in the upper 5 cm than the conventional-tillage (CT) fields (12.6 versus 8.3 Mg ha$^{-1}$ [5.6 versus 3.7 tn ac$^{-1}$]). Particulate organic matter-C accumulations in the upper 5 cm of the soil profile were also significantly greater in the NT fields than in two of the three CT fields (fields 3 and 6). Field 2, however, had significantly more MIN-C than both of the other CT fields and more MIN-C than field 3. The accumulation of POM-C in the upper 5 cm of field 2 was also similar to those in the NT fields. Variation of MIN-N in the upper A horizon among fields was generally similar to variation in C. Carbon and N pools were similar among fields at the 5 to 10 cm (2 to 4 in) depth. Quantities of MIN-C, POM-C, and MIN-N in the Bt horizon were low and similar among fields. Concentrations of POM-N in the Bt horizons were at or below the minimum for reliable quantification, so those values were not reported.

The SOC content of the fields prior to the use of NT is not known, so we cannot conclusively confirm that the use of NT has increased SOC in individual fields. However, the consistently greater SOC pools in NT fields, compared to CT fields, are a strong indication that C has been sequestered. Moreover, each of the NT fields had a long history of CT before adaptation of NT in the 1990s. This suggests that CT and NT fields would have had similar SOC accumulations prior to conversion to NT. The years that cultivation was initiated on the individual fields is not known, but most prime farmland in the valley was cleared and planted to grain and forage crops by the mid 1800s. Therefore, at least 100 years of similar management can be assumed for all fields before NT was used. If both MIN-C and POM-C are included, the average C content of the upper 5 cm (2 in) of the NT fields was about 6 Mg ha$^{-1}$ (2.7 tn ac$^{-1}$) greater than the CT fields. Over the average of 11 years since NT has been adopted on these fields, the data suggests that C has accumulated at a rate of about 0.5 Mg ha$^{-1}$ yr$^{-1}$ (0.2 tn ac$^{-1}$ yr$^{-1}$). This sequestration rate is at the upper end of the range of 0.1 to 0.5 Mg C ha$^{-1}$ yr$^{-1}$ (0.05 to 0.2 tn ac$^{-1}$ yr$^{-1}$) that can typically be expected following the conversion to conservation tillage (Lal et al. 1998). Additionally,
much of the difference in SOC between CT and NT fields was accounted for in the MIN fraction. Therefore, much of the added SOC in NT fields is likely incorporated into clay-protected and other recalcitrant SOM pools with slow turnover. The average of approximately 50% greater C accumulations in surface soils from NT fields in the current study is also similar to SOC increases with NT reported by Duiker and Beegle (2006). They found that continuous NT grain corn production for 25 years on Hagerstown and Hublersburg soils (near our field 6) resulted in 31% and 72% increases in SOC concentration in the upper 5 cm of soil compared to the use of chisel disk and moldboard disk systems, respectively.

Since the surveyed fields were maintained in silage corn-alfalfa rotations, little above-ground crop residue was returned to the soil. It is reasonable to predict that the lack of stover inputs could result in lower C sequestration rates than would be predicted with grain corn production. However, our NT fields contained substantially more C in the upper 5 cm (2 in) of soil than CT fields, suggesting that above-ground residues may not be critical for the sequestration of SOC. Measurements by Hooker et al. (2005) showed SOC gains with NT that were comparable to this study, regardless of whether or not stover was removed from the field. Increased C sequestration, with the elimination of tillage, results primarily from slower turnover of SOC and root residues caused by reduced aeration, lower temperature, and much less physical breakdown of plant residues (Lal et al. 1998). These impacts of NT and the slower decomposition of root, compared to shoot, residues explain the diminished importance of above-ground residues as a source of sequestered C (Balesdent and Balabane 1996; Bolinder et al. 1999).

Since little variation in organic C pools was seen among the Bt horizons, discussion of the associated properties will be limited to the two layers sampled from the A horizon. Variation in soil aggregate stability (figure 2a) among fields followed a trend very similar to that of the soil C pools. The combination of NT and CC resulted in the greatest aggregate stability with fields 1 and 7 (NT, CC) having up to two times more stable aggregates (>0.5 mm) than field 4 and 5 (NT, no CC) and over four times more than fields 3 (CT, no CC) and 6 (CT, CC). Greater aggregate stability

Notes: Farms used either conventional tillage or no-till, and rye cover crops were used on some fields. Means for each field include data from both 2003 and 2004. Error bars are the standard errors (n = 6). Means for the same depth accompanied by the same letter do not differ significantly (p ≤ 0.10) among fields. The symbol ** above a bar indicates a significant difference (p ≤ 0.10) between 0 to 5 cm and 5 to 10 cm depth within the same field.
indicates improved soil structure facilitating root growth and water movement, which can decrease the soil's susceptibility to erosion. The increases in aggregate stability with greater soil C observed here are consistent with the belief that organic materials are important cementing agents active in the formation and stabilization of soil aggregates (Jastrow 1996; Six et al. 1998).

Cation exchange capacity (figure 2b) in the upper 5 cm (2 in) was generally greater in NT fields and followed trends in C accumulation. Soil organic matter typically has a CEC of about 200 cmol+ kg⁻¹ (Brady 1974). Therefore, the greater CEC in the NT fields appears to be the direct result of the large nutrient holding capacity provided by the additional SOM. While mean CEC's of the 5 to 10 cm (2 to 4 in) depths were larger in the NT fields, variation within the NT fields was high, and field means were generally not significantly different.

Farmers are often concerned that adopting NT will result in soil compaction (Logsdon and Cambardella 2000). However, in this study, mean Dh of the upper 5 cm (2 in) was lower for all NT fields compared with the CT fields (although not significant at p ≤ 0.10 in all cases) (figure 2c). There was no consistent trend in Db differences among fields at the 5 to 10 cm (2 to 4 in) depth, but NT fields had a consistently greater Db in the 5 to 10 cm depth compared to the upper 5 cm (2 in) in the same fields. While our data does not provide conclusive evidence to show a reduction in Db with the use of NT, our data does indicate that the commonly expected increases in soil compaction with the introduction of NT either did not occur on these fields or that initial increases in Db diminished with time.

We anticipated that a decrease in soil C pools would be seen between sampling years in CT fields. Our hypothesis was that C would accumulate in the absence of tillage during the four, or more, years of alfalfa but would be gradually lost due to tillage in corn years of the rotation. However, we found no detectable change in C pools between sampling years in any of the fields (data not shown) even in fields 2 and 4, which were originally sampled at the end of the first year of corn after alfalfa. Assuming that soil C did increase during the years alfalfa was grown, much of the C might have been rapidly lost when the fields were tilled and throughout the first season in which corn was planted.
However, the rate of C loss after plowing under a perennial crop is not well documented. Staley and Boyer (1997) established silage corn production on a former pasture using both NT and intensive tillage. When SOC was measured shortly after tillage and planting of the initial corn crop, they found substantially less SOC in CT plots compared to NT. However, SOC changed little from those first measurements through the end of four growing seasons, leading the authors to conclude that differences in SOC between CT and NT plots were primarily caused by losses immediately following the initial tillage operations. Reicosky (1997) found that over a 19-day period immediately following various tillage operations, 54% to 134% of the SOC content of the previous crop's residue production was released as CO2. While his results do not directly describe the rate of C loss when a crop rotation switches from a perennial crop to a tilled annual crop, they do demonstrate that a substantial quantity of accumulated C can be lost shortly following tillage.

**Cover Cropping Related Trends.** The impact of CC on the measured properties was not conclusive. For both CT and NT fields, MIN-C and POM-C were similar among fields regardless of CC (figure 1). Cover cropping affected N accumulations in some cases. Both MIN-N and POM-N were significantly greater in the upper 5 cm (2 in) of field 6 (CT, CC) than field 2 (CT, no CC), and fields 1 and 7 (NT, CC) had significantly more MIN-N in the 0 to 5 cm (0 to 2 in) layer than field 4 (NT, no CC). Several studies have shown the ability of CCs to take up excess nitrate leading to its retention within SOM (Kuo et al. 1997; McCracken et al. 1994; Sainju et al. 2007). The measurement of larger soil organic N pools suggests that reduced N losses are also associated with CC (see table 1). However, the application of manure to CC fields did not appear to impact C pools compared to other NT fields. In NT fields, bedding materials added with manure decompose on the surface and would likely have less impact on soil C pools than if they had been incorporated by tillage.

Textures of surface soils at the sites varied among loam, silt loam, silty clay, and silty clay loam (table 1), even though all sampling locations (except field 7) were classified as the Hagerstown series. Clays contribute to CEC and can protect SOM from decomposition, so silty clay and silty clay loam soils potentially would have greater CEC and accumulations of organic C and N than loam or silt loam soils. Nevertheless, measured properties did not correspond consistently with soil texture. Tillage produced the only clear differences among fields.

**Implications.** There are approximately 180,000 ha (445,000 ac) of silage corn planted each year in Pennsylvania (USDA National Agricultural Statistics Service), and intensive tillage is still used on approximately 50% of the cropland in the state (PSU Agronomy Guide). Assuming a moderate C sequestration rate of 0.3 Mg ha\(^{-1}\) yr\(^{-1}\) (0.13 tn ac\(^{-1}\) yr\(^{-1}\)), eliminating intensive tillage on silage corn acreage in Pennsylvania could return 27,000 Mg C yr\(^{-1}\) (29,800 tn C yr\(^{-1}\)) to the soil. Total greenhouse gas emissions for Pennsylvania are estimated to be approximately 80 million Mg (88 million tn) of carbon equivalents per year (Rose et al. 2005). While the potential increase in C sequestration from eliminating tillage on silage corn acreage offsets only a small fraction of annual greenhouse gas emissions from the state, greater adoption of NT production on a wider array of crops can make a meaningful contribution towards achieving targeted CO2 emission reductions.

**Summary and Conclusions.** Our survey of silage corn fields on central Pennsylvania dairy farms showed that accumulations of SOC were 3 to 6 Mg ha\(^{-1}\) (1.4 to 2.8 tn ac\(^{-1}\)) greater in the upper 5 cm (2 in) of soil where NT had been used for 8 to 13 years, compared to CT fields. Soil organic C accumulations from 5 to 10 cm (2 to 4 in) below the surface and in the upper Bt horizon were generally similar among fields. Soil aggregate stability and CEC were proportional to the accumulation of SOC. The rate of C sequestration with the adoption of NT estimated from these on-farm measurements (0.5 Mg ha\(^{-1}\) yr\(^{-1}\) [0.2 tn ac\(^{-1}\) yr\(^{-1}\)]) validates the expected gains of 0.1 to 0.5 Mg C ha\(^{-1}\) yr\(^{-1}\) (Lal et al. 1998) compiled from reports of plot-scale experiments. Our data were less conclusive concerning the impact of CC on soil C and N accumulation and soil properties. While no evidence of increased C sequestration was observed when rye CC was used, N accumulations were generally greater when CC was used demonstrating the known ability of the rye plants to capture nitrate and retain that N within the rootzone. The combined use of NT and CC resulted in the greatest soil aggregate stability, and merits further research. While soil erosion control will likely remain the most pressing reason for the expansion of NT and CC, the current study suggests that dairy farmers in our region who use NT can sequester C and improve soil properties, as suggested by the results of plot-scale research.

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