# SURFACE SOIL ORGANIC POOLS IN RESPONSE TO SILAGE CROPPING INTENSITY UNDER NO TILLAGE

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## ABSTRACT

**Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues returned to soil will likely alter the success of a particular conservation tillage system within a farm operation. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil organic matter pools in different environments. We investigated the impact of three cropping systems (a gradient in residue returned to soil) on total organic C and N, particulate organic C and N, microbial biomass C, and mineralizable C and N in a Piedmont soil in North Carolina. There is an inverse relationship between silage intensity and residue returned to soil. With time, surface soil organic matter pools became higher with reduced silage cropping intensity as a result of greater crop residue returned to soil. These results suggest that greater quantities of crop residue returned to soil have positive effects on soil organic matter pools in continuous no-tillage crop production systems. These results can help to determine an optimum balance between short-term economic returns and longer term investments in improved soil quality for more sustainable production.**

## INTRODUCTION

Soil quality is a concept based on the premise that management can deteriorate, stabilize, or improve soil ecosystem functions. Soil provides a medium for plant growth, regulates and partitions water flow in the environment, and buffers the fluxes of natural and xenobiotic compounds through decomposition and fixation processes (Larson and Pierce, 1991). The organic components of soil are important in providing energy, substrates, and the biological diversity necessary to sustain many soil functions.

Conservation tillage systems are now widely adopted by many producers, because they

- reduce fuel, time, and labor needed to make multiple tillage operations,
- reduce machinery wear
- allow for more timely planting of crops even under wetter soil conditions
- improve soil and water quality
- reduce runoff and make more effective use of precipitation
- improve wildlife habitat
- meet Farm Bill requirements

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a farm operation. Crop residues left at the soil surface as a surface mulch are important for feeding the soil biology, suppressing weed seed germination, and suppressing wide fluctuations in temperature and moisture that can hinder plant development. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments.

Dairy producers in North Carolina rely on corn and barley silage as sources of high quality feedstuffs in their rations. High-intensity silage cropping is typically practiced to maximize the amount of feedstuffs produced per unit of land area. High-intensity silage cropping, however, leaves little residue at the soil surface, offering little buffer against equipment traffic. The lack of residue returned to the soil under high-intensity silage cropping brings into question issues of low soil biological activity, long-term compaction, inefficient water-use, poor nutrient cycling, and soil erosion even when conservation tillage is used.

We investigated the impact of alternative, reduced-silage-cropping-intensity systems that returned more crop residues to the soil than the traditional maize-barley silage cropping system on surface-soil properties. We consider the soil surface a critical component of agroecosystems, because it is the vital interface that initially determines the fate of fertilizers, pesticides, water, and gases into and out of the soil profile.

## MATERIALS AND METHODS

The site is located in Iredell County in the Southern Piedmont Major Land Resource Area of North Carolina. Soils are mostly Fairview sandy clay loam (fine, kaolinitic, mesic Typic Kanhapludult) in Replication 1 and Braddock loam (fine, mixed, semiactive, mesic Typic Kanhapludult) in Replication 2. These soils are classified as well drained with moderate permeability. Mean annual precipitation is 48" and mean annual temperature is 58 EF.

Three cropping systems replicated twice were evaluated in –1000-ft-long strips that were 40-67-ft wide each. Plots were managed by the owner with his field equipment. Replication 1 was established in 1998 and Replication 2 was established in 2000. All plots were managed with no tillage for several years prior to, as well as during experimentation. Previous management of the field with no tillage was without high residue input. Prior to no tillage, this field was managed with a 2- to 4-year rotational strip cropping system of perennial forage with maize silage. Fertilizer as liquid dairy manure was applied in spring at a rate of 1930 to 2360 gal/acre/yr, which was equivalent to 40-31-100-7 lb N-$P_2O_5$-$K_2O$-S/acre.

The three cropping systems were designed as a gradient in silage intensity and inversely related to the amount of crop residues returned to the soil. The traditional cropping system (high silage intensity) was maize silage planted in May and harvested in September followed by barley silage planted in November and harvested in April. This was a one-year rotation and had the least above-ground residue returned to the soil. A medium silage intensity system was maize silage planted in May and harvested in September followed by a winter cover crop (rye alone or rye plus crimson clover) killed by a herbicide in April. This was a one-year rotation and had a moderate level of crop residue returned. A low silage intensity system was maize silage planted in May and harvested in September followed by barley planted in November and harvested for grain in June. Barley straw was left in the field and a summer cover crop (sudangrass or sunnhemp) planted in June and killed by frost in October. The summer cover crop was left in the field and followed by planting of rye as a winter cover crop in November, which was killed by a herbicide in April and left in the field. This was a two-year rotation and had the highest level of crop residue returned. Expressed as silage cropping intensity, treatments had 1 (low silage intensity), 2 (medium silage intensity), and 4 (high silage intensity) silage crops harvested during a 2-year period.

Surface residue and soil were sampled in December 2000, February 2002, and November 2002. In December 2000, plots were sampled in duplicate by splitting the plot in half to assess within-plot variability. For each sample collected, eight sites located –67 ft apart were composited. Surface residue was collected from 8 x 8" areas by first removing green plant material above –2" height and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core (1-5/8" diam) was sectioned into depths of 0-1.2", 1.2-2.4", 2.4-4.7", and 4.7-8". Soil was dried at 131 EF for 3 days, initially passed through a sieve with openings of 3/16" to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device.

Particulate organic matter was isolated from soil by shaking 0.7- to 2.3-oz subsamples of soil in 3.5 oz of 0.01 *M* $Na_4P_2O_7$ for 16 hr, passing the mixture over a sieve with 0.002" openings, and collecting the material >0.002". Samples were dried at 131 EF for 24 hr past visual dryness, weighed, ground to a fine powder in a ball mill, and analyzed for C and N concentration with dry combustion.

Potential C mineralization was determined by placing two 0.7- to 2.3-oz subsamples (inversely related to soil organic C concentration) in 2-oz glass jars, wetting to 50% water-filled pore space, and placing them in a 1-qt canning jar along with 0.35 oz of 1 *M* NaOH to trap $CO_2$ and a vial of water to maintain humidity. Samples were incubated at 77 EF for up to 24 d. Alkali traps were replaced at 3 and 10 d of incubation and $CO_2$-C determined by titration with 1 *M* HCl in the presence of excess $BaCl_2$ to a phenolphthalein endpoint. At 10 d, one of the subsamples was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, vapors removed at 24 hr, placed into a separate canning jar along with vials of alkali and water, and incubated at 77 EF for 10 d. Soil microbial biomass C was calculated as the quantity of $CO_2$-C evolved following fumigation divided by an efficiency factor of 0.41.

Since the two replications in this experimental design were established two years apart, we chose to look at the temporal changes that occurred in soil properties through regression, rather than discrete sampling year effects. Sampling in December 2000 was after 3 years (Replication 1) and 1 year (Replication 2). Sampling in February 2002 was after 4 years (Replication 1) and 2 years (Replication 2). Sampling in November 2002 was after 5 years (Rep 1) and 3 years (Replication 2). Stratification ratio of soil properties was calculated from the concentration at a depth of 0-2.4" divided by the concentration at a depth of 4.7-8". Treatment means averaged across sampling events were evaluated for differences with a paired t-test. Differences among silage cropping intensity treatments were considered significant at *p*#0.1.

## RESULTS AND DISCUSSION

Soil organic C averaged across all three sampling events was not significantly different among cropping systems (data not shown). Soil organic C of the surface 1.2" increased with time under low silage intensity, did not change with time under medium silage intensity, and decreased with time under high silage intensity (Fig. 1). These results are attributable to the expected return of crop residues to the soil surface in each of these three cropping systems.

Soil microbial biomass C of the surface 1.2" followed a pattern similar to that of soil organic C (Fig. 2), although there was a tendency for soil microbial biomass C to decline during the 5th year under low silage intensity. It is possible that the dry conditions of 2002 may have reduced soil microbial biomass C in the 5th year. Soil microbial biomass C as a percentage of total organic C was 4.8 $\pm$ 1.0%. It plays a major role in organic matter decomposition and nutrient cycling, and therefore, may be an early indicator of long-term changes in soil organic matter (Powlson et al., 1987). Soil microbial biomass is an important mediator in several nutrient cycles and biophysical manipulation of soil structure.

Potential C mineralization from the surface 1.2" of soil during 24 days of aerobic incubation did not change with time under low and medium silage intensity, but tended to increase with time under high silage intensity (Fig. 3). However when averaged across sampling times, potential C mineralization was 0.19 $\pm$ 0.06% under low silage intensity, 0.18 $\pm$ 0.03% under medium silage intensity, and 0.12 $\pm$ 0.02% under high silage intensity. Potential C mineralization reflects the quality and quantity of substrates available for utilization by soil heterotrophic microorganisms, which can affect short-term N and P mineralization/immobilization and long-term storage and subsequent slow release of nutrients. The results of this study suggest that surface soil is more enriched in mineralizable C with more crop residue returned.

Net N mineralization from the surface 1.2" of soil during 24 days of aerobic incubation declined during the first few years of management under low and medium silage intensity and tended to increase with time under high silage intensity (Fig. 4). The accumulation of surface residues with high C-to-N ratio probably contributed to the reduced net N mineralization with lower silage intensity, because soil microorganisms were active in processing the heavy load of organic C at the soil surface. Our analyses of surface residues are yet incomplete, but mass of surface residues was 2.46 $\pm$ 1.22 ton/acre with high silage intensity, 3.38 $\pm$ 1.02 ton/acre with medium silage intensity, and 3.26 $\pm$ 0.37 ton/acre with low silage intensity. The C-to-N ratio of the mineralizable fraction reflected this additional workload of surface soil microrganisms, whereby C-to-N ratio increased greatly with time under low silage intensity, moderately with medium silage intensity, and remained at a low level with time under high silage intensity (Fig. 5).

Stratification of soil organic matter under conservation tillage systems is a natural consequence of crop residues left at the soil surface to decompose without alteration by tillage. The degree of stratification of various soil organic matter pools has been proposed as an indicator of soil quality or soil ecosystem functioning, because surface organic matter is essential to erosion control, water infiltration, and conservation of nutrients (Franzluebbers, 2002a). Increased stratification is likely to (1) improve water efficiency by reducing runoff and increasing retention in soil, (2) improve nutrient cycling by slowing mineralization and immobilizing nutrients in organic fractions rather than losing them in runoff and leachate, (3) resist degradative forces of wind and water erosion and mechanical compaction, (4) improve soil biological diversity, and (5) enhance long-term productivity of soils.

Stratification ratio of soil organic C did not change dramatically in any of the three cropping systems and was not different among cropping systems when averaged across sampling events (4.2 $\pm$ 1.3) (Fig. 6). There was a tendency for divergence in the stratification ratio of soil organic C between medium silage intensity and high silage intensity. Stratification ratio of soil microbial biomass C was greater ($p$ = 0.09) under low silage intensity (4.6 $\pm$ 1.3) than under high silage intensity (3.5 $\pm$ 0.5) and intermediate with medium silage intensity (4.2 $\pm$ 0.9). In a similar manner, stratification ratio of the flush of $CO_2$-C during 3 days following rewetting of dried soil was greater ($p$ = 0.03) under low silage intensity (6.0 $\pm$ 1.8) than under high silage intensity (4.3 $\pm$ 1.1) and intermediate under medium silage intensity (5.5 $\pm$ 1.2). Interestingly, however, there was no strong trend for changes in stratification ratios with time. It is possible that the relatively high stratification ratios in all systems at the beginning of this study, due to several previous years of no tillage silage production at this site, may have been near the upper level of values that are likely to occur within a decade of continuous management. The upper limits for this region have not been described, but ratios of various soil organic matter pools peaked at values of 4 to 10 in several evaluations of management systems in Alberta, Georgia, and Texas (Franzluebbers, 2002a). In a controlled experiment, infiltration of water into soil was maximized when a Typic Kanhapludult had a stratification ratio of soil organic C $\geq$5 (Franzluebbers, 2002b).

Previous results from this study suggested that surface compaction was occurring at a steady rate with high silage cropping intensity and that compaction could be alleviated by low silage cropping intensity with high surface residue return (Franzluebbers et al., 2003). The slow conversion of organic matter from crop residues into soil organic C, especially at the soil surface, can lead to a large reduction in soil bulk density (Franzluebbers, 2002b). Organic matter has a much lower specific density than mineral soil and the incorporation of organic matter with soil often leads to a more porous soil matrix as a result of soil faunal and microbial activity, which create water-stable aggregates.

## CONCLUSIONS

Sampling of surface-soil properties within the first 5 years of implementation of alternative silage crop management systems suggested that soil biochemical properties such as organic C, microbial biomass C, and potential C mineralization responded positively and led to an improvement in soil quality. Soil organic C pools were highly stratified with depth under all management systems in this study as a result of long-term management with conservation tillage. Return of organic substrates to the soil surface were necessary to maintain high surface-soil biological activity, which would foster water and nutrient efficiency and prevent soil compaction. Sufficient quantities of residues returned to the soil are necessary for organic matter transformations to facilitate the development of an improved soil condition.

## ACKNOWLEDGEMENTS

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## LIST OF FIGURES

Fig. 1. Temporal changes in soil organic C at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

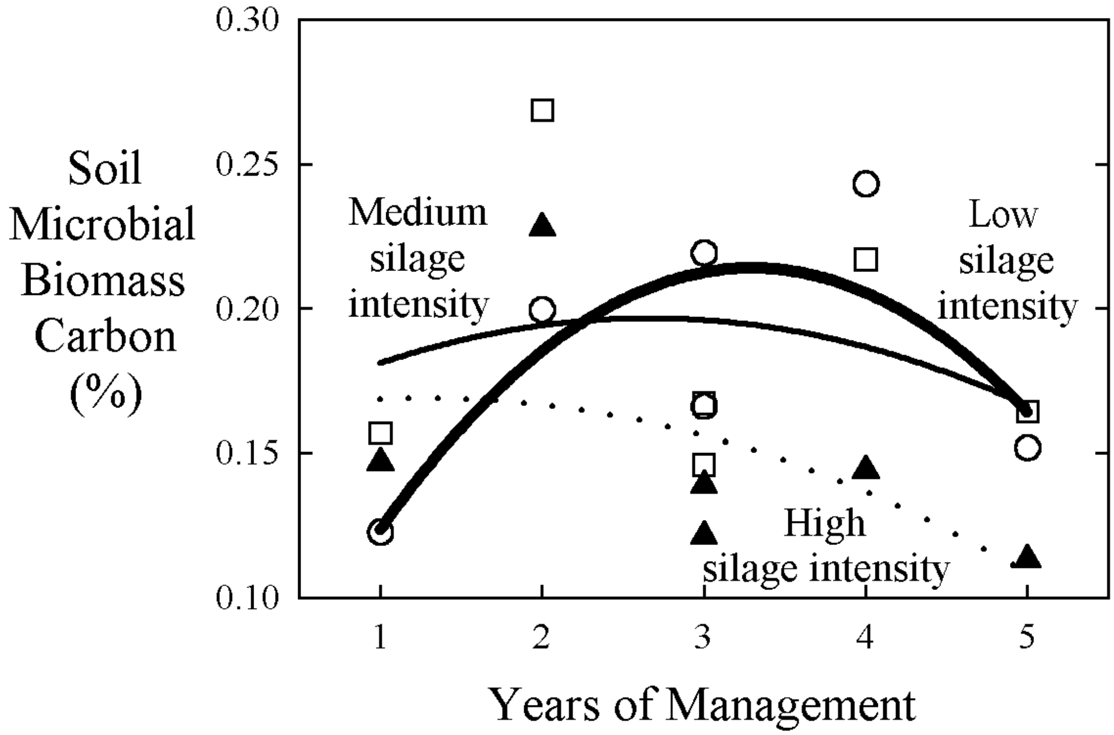
Fig. 2. Temporal changes in soil microbial biomass C at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

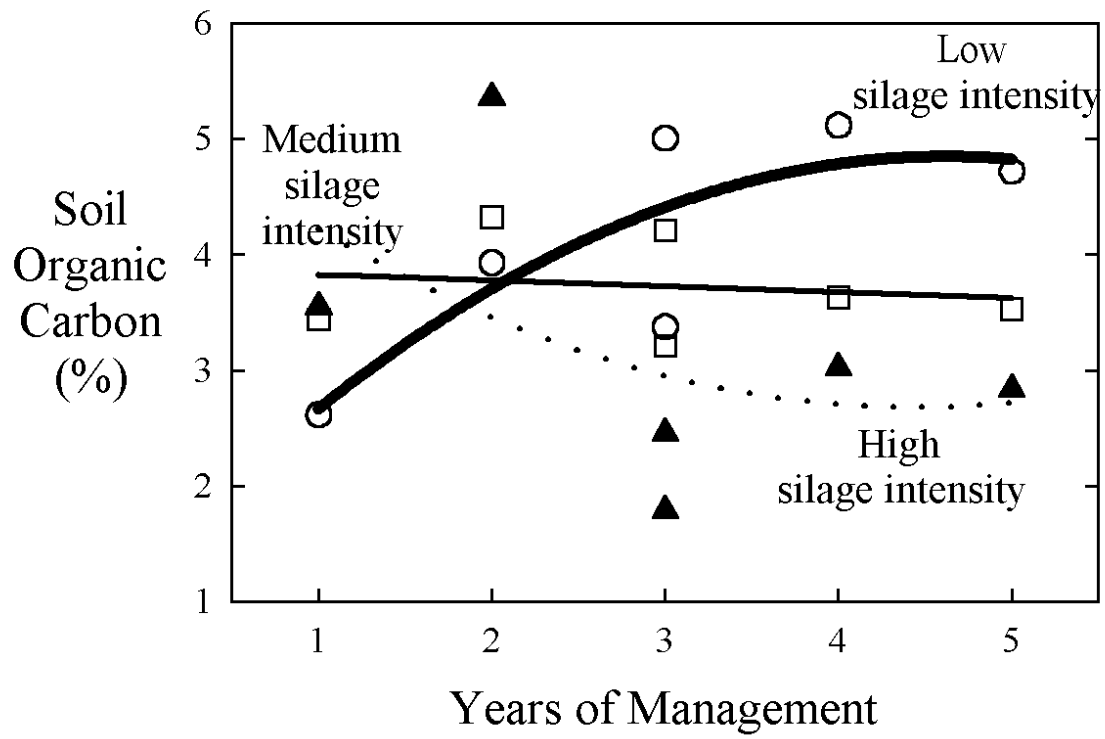
Fig. 3. Temporal changes in potential C mineralization at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

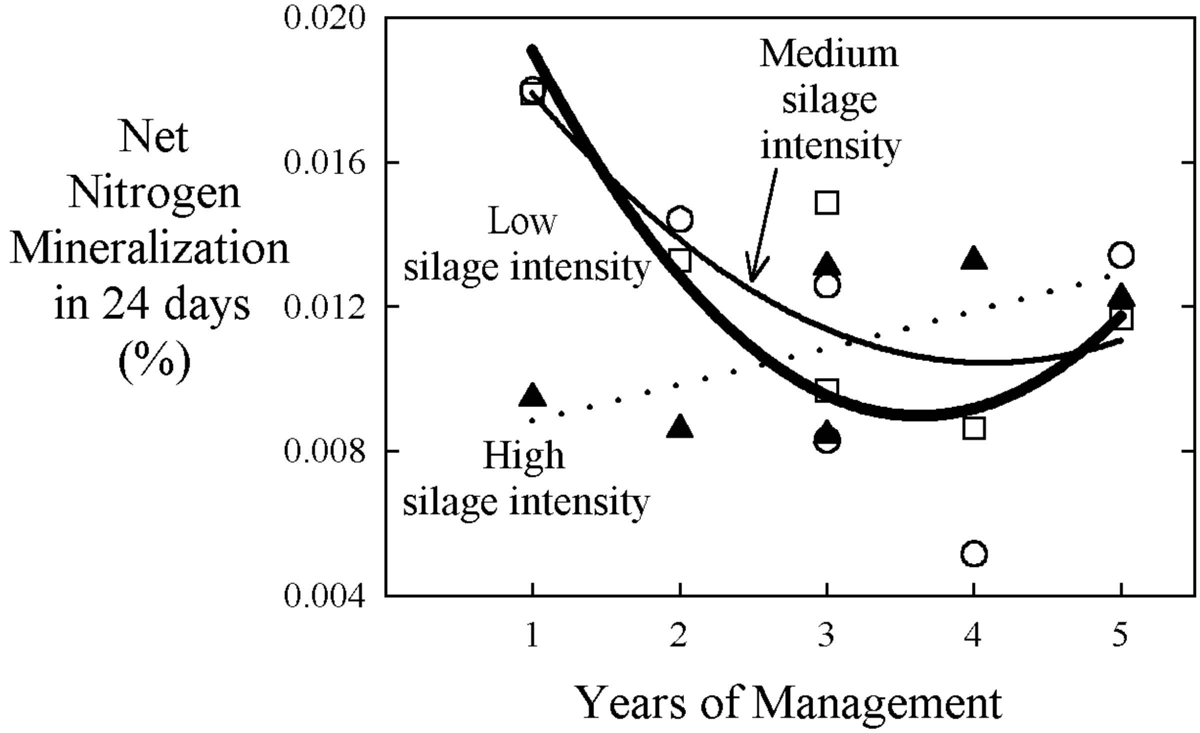
Fig. 4. Temporal changes in net N mineralization at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

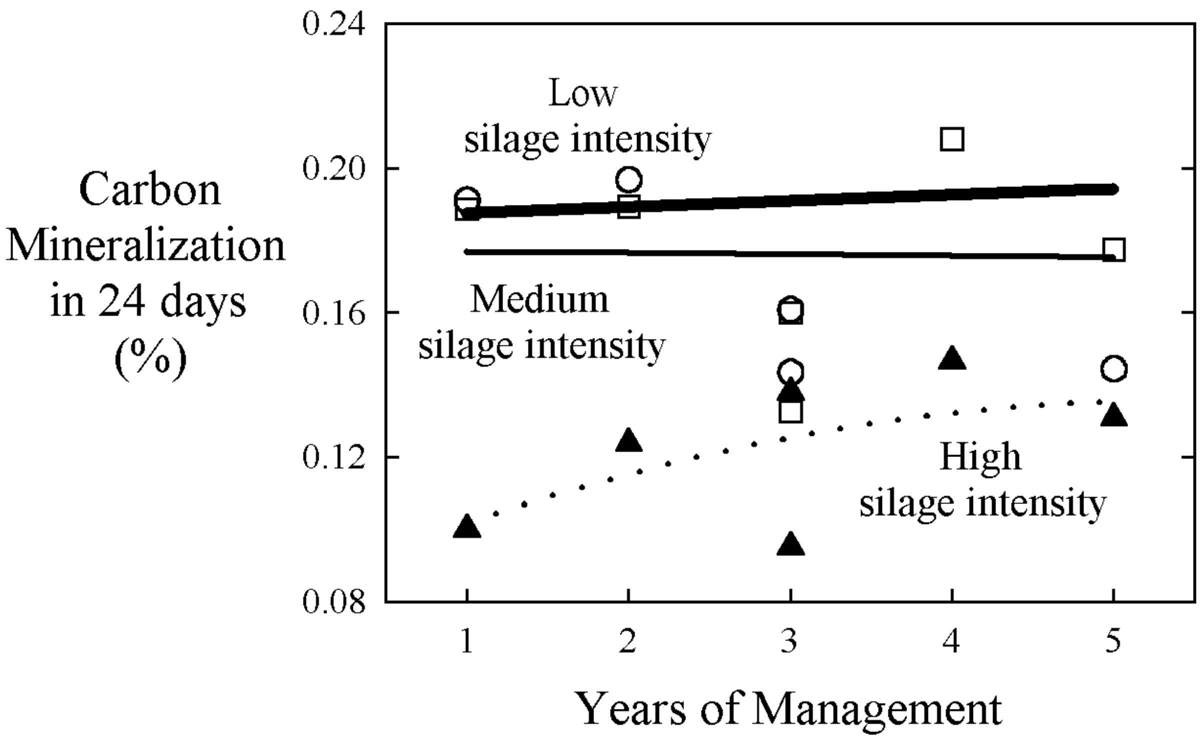
Fig. 5. Temporal changes in the mineralizable C-to-N ratio at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

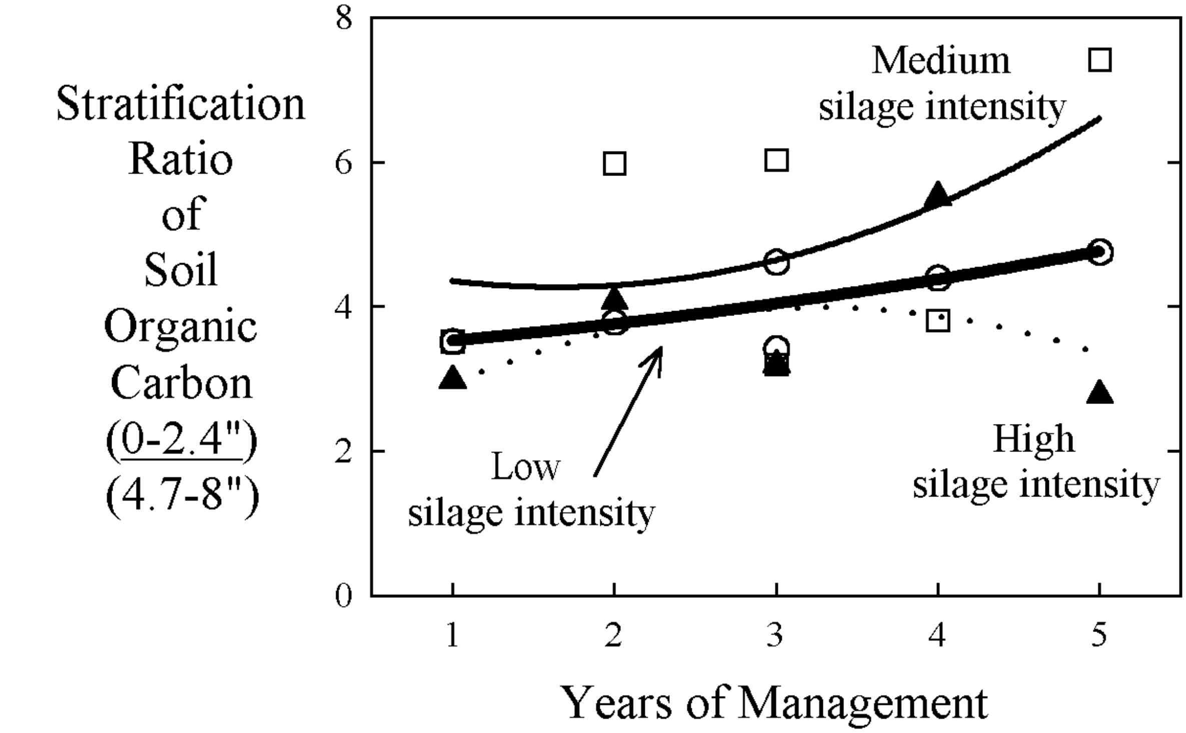
Fig. 6. Temporal changes in the stratification ratio of soil organic C as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

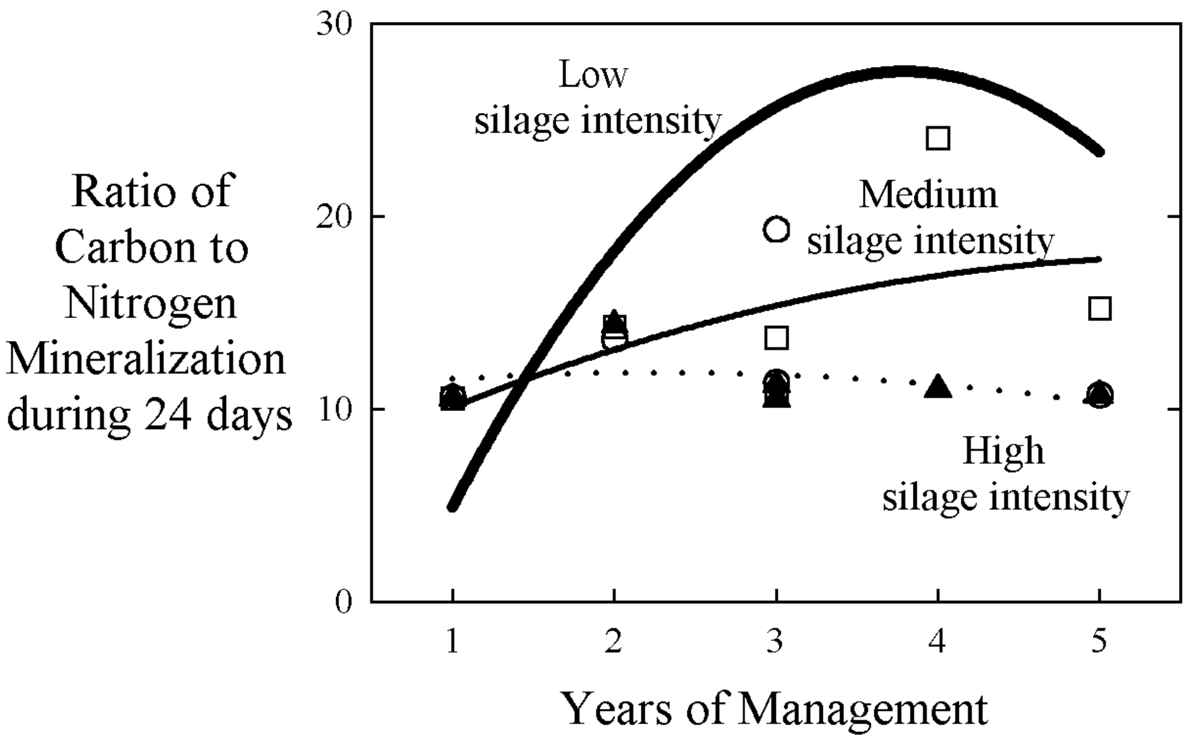

Soil Microbial Biomass Carbon (%)
0.30
0.25
0.20
0.15
0.10
Medium silage intensity
Low silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Soil Organic Carbon (%)
6
5
4
3
2
1
Low silage intensity
Medium silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Net Nitrogen Mineralization in 24 days (%)
0.020
0.016
0.012
0.008
0.004
Medium silage intensity
Low silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Carbon Mineralization in 24 days (%)
0.24
0.20
0.16
0.12
0.08
Low silage intensity
Medium silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Stratification
Ratio
of
Soil
Organic
Carbon
(0-2.4")
(4.7-8")
8
6
4
2
0
Medium
silage intensity
Low
silage intensity
High
silage intensity
1
2
3
4
5
Years of Management


Ratio of
Carbon to
Nitrogen
Mineralization
during 24 days
30
20
10
0
Low
silage intensity
Medium
silage intensity
High
silage intensity
1
2
3
4
5
Years of Management