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Impact of Crop Rotations and Winter Cover Crops on Vegetative Cover, Aboveground Biomass, and Soil Organic Matter under No-Till in Western Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Nicholas Phillip Ryan entitled "Impact of Crop Rotations and Winter Cover Crops on Vegetative Cover, Aboveground Biomass, and Soil Organic Matter under No-Till in Western Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Sciences.

Forbes Walker, Major Professor

We have read this thesis and recommend its acceptance:

Daniel Yoder, Donald Tyler

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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IMPACT OF CROP ROTATIONS AND WINTER COVER CROPS ON VEGETATIVE COVER, ABOVEGROUND BIOMASS, AND SOIL ORGANIC MATTER UNDER NO-TILL IN WESTERN TENNESSEE

A Thesis Presented for the Master of Science Degree
The University of Tennessee, Knoxville

Nicholas Phillip Ryan
December 2007

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Abstract

We investigated, under long-term no-till in western Tennessee, the effects of rotating the low-input crops cotton and soybeans with the high-input crop corn, compared to continuous monocultures of cotton and soybeans, and of using the winter cover crops (WCCs) winter wheat and hairy vetch, compared to winter fallow, on key indicators of soil health concerning vegetative cover and labile SOM. The line-transect method was used to measure percent vegetative cover. Dry weight of surface crop residue and aboveground living plant biomass (WCCs and winter weeds) was obtained. The living plant biomass was analyzed for carbon (C) and nitrogen (N) by dry combustion to determine C/N ratios. The sand-sized POM-C fraction at 0 to 5 and 5 to 15 cm was physically fractionated and analyzed for C by dry combustion. The inclusion of corn in rotation with cotton significantly increased aboveground crop residue quantity, aboveground winter weed biomass quantity, total aboveground biomass quantity, percent vegetative cover, and POM-C at 0 to 5 cm. The inclusion of corn in rotation with soybeans significantly increased aboveground crop residue quantity and POM-C at 0 to 5 cm, but significantly decreased aboveground winter wheat biomass quantity, total aboveground biomass quantity under winter wheat, aboveground winter weed biomass C/N ratio, and POM-C at 5 to 15 cm. The use of WCCs did not significantly increase total aboveground biomass quantity under most cropping sequences, and significantly reduced aboveground crop residue quantity, aboveground winter weed biomass quantity, and percent vegetative cover. The WCCs generally did not affect POM-C at either depth, though they significantly increased POM-C at 5 to 15 cm under continuous soybeans. Compared to winter wheat, hairy vetch significantly increased aboveground winter weed biomass quantity and percent vegetative cover. Our results demonstrate that the inclusion of corn in rotation with cotton is highly effective, while inclusion of corn in rotation with soybeans and the use of WCCs are ineffective in improving soil quality by increasing vegetative cover and the labile pool of SOM under these conditions.

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Nomenclature

^{0}C	degrees Celsius
cm	centimeter
gt	gigaton
mg	megagram
ha	hectare
kg	kilogram
L	liter
m	meter
mL	milliliter
m.y.	million years
mm	millimeter
µm	micrometer
yr	year

List of Abbreviations

C	carbon
CO_2	carbon dioxide
F:B	fungi to bacteria ratio
N	nitrogen
NO_3	nitrate
POM	particulate organic matter
RUSLE	Revised Universal Soil Loss Equation
SOM	soil organic matter
SOC	soil organic carbon
WCC	winter cover crop

I. LITERATURE REVIEW

Since the dawn of agricultural civilizations, the careful management of soils has been fundamental to the success and longevity of population centers and even entire cultures (Mann, 2000; Conway Morris, 2003; Gregorich et al., 2006; Montgomery, 2007a). Nevertheless, throughout the development of agriculture up to this day, humans have not always been vigilant regarding soil care and thus have suffered the serious economic and environmental consequences (Tilman, 1998). Sustaining the health of the soil, or soil stewardship, involves tending the soil to keep it productive for the current generation, as well as preserving it for use by future generations (Gregorich et al., 2006). Taking care of the soil resource in the 21st century is of the utmost importance, especially as the rapidly growing global population demands more from the soil and encroaches more and more upon the area of land that is suitable for agriculture (Rasmussen et al., 1998; Huang et al., 2002).

In the 1990s, the scientific community of the environmental movement shifted focus from monitoring human activities that degraded natural resources towards a more holistic approach characterized by evaluating ecosystem health. Integral to the ecosystem health model was soil quality, defined as “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Smith and Collins, 2007). The maintenance and improvement of soil quality--or soil health--

through crop and soil management is crucial to the long-term sustainability of agricultural systems (Reeves, 1997). Not unlike the use of indicators for objectively evaluating economic performance, an increasingly common approach in the agricultural sector has been to use indicators to assess the sustainability of agricultural systems. Soil quality indicators include a broad variety of measurable physical, chemical, and biological processes and properties of soil that are essential to the soil's ability to perform specific desired functions (Gregorich et al., 2006).

Soil Organic Matter and Soil Quality

Soil organic matter (SOM), or humus, is probably the most important indicator of soil quality, owing to its influence on other soil physical, chemical, and biological indicators (Gregorich et al., 2006). Though soils with low SOM can be manipulated through agrochemical and technology inputs (i.e., fertilizers, irrigation, pesticides, tillage, soil amendments) to produce high crop yields, the long-term health of the soil is most improved by building up and maintaining SOM (Sparling et al., 2006). Soil organic matter supplies large amounts of carbon (C) as an energy source for soil fauna and flora, stores and makes available macronutrients and micronutrients, and complexes with clay minerals coated with metal oxides to form stable aggregates. An improvement in soil aggregation in turn reduces erosion and enhances the infiltration of water and gases into the soil (Sparks, 2003; Essington, 2004; Gregorich et al., 2006). Soil organic matter reduces the mobility and availability of metal contaminants by complexing and chelating metal cations, contributes to the retention of pesticides and other organic substances, is responsible largely for the capacity of soil to buffer soil solution pH, and provides a sizable portion of the cation exchange capacity of soil. In addition, SOM enhances the water-holding capacity of soil, accelerates the dissolution of soil minerals, and influences soil thermal properties (Sparks, 2003; Essington, 2004). The adoption of management practices that increase the sequestration of carbon dioxide (CO_2) as stable SOM reduces the contribution of agricultural soils to atmospheric concentrations of greenhouse gases (Bell et al., 2003).

Excluding fresh and partially decomposed plant and animal residues, SOM fundamentally consists of diverse organic compounds in different stages of decomposition, including the non-humic substances, which belong to known classes of biochemistry, and the dark-colored refractory compounds that do not belong to such classes, known as humic substances (Sparks, 2003; Essington, 2004). In addition, soil scientists have conceptually grouped SOM according to differences in susceptibility to microbial degradation, as the labile pool consisting of materials readily transformed by microorganisms, and the passive pool consisting of materials resistant to further microbial metabolism (Haynes, 2005; Brady and Weil, 2007). Labile fractions of SOM have a shorter turnover time than that of total SOM. Their measurement, therefore, is useful for evaluating early changes in soil health in response to changes in management, such as tillage or cropping systems (Wander, 2004). Some of the more commonly used labile SOM fractions include dilute acid-extractable polysaccharides (Liu et al., 2005), microbial biomass C (Mendes et al., 1999), dissolved organic carbon, hot water-extractable SOM, permanganateoxidizable C (Weil et al., 2003), potentially mineralizable C and nitrogen (N) (Haynes, 2005), and particulate organic matter (POM) (Wander, 2004). In the southeastern United States, where SOM is low relative to that in other regions of the country (Katsvairo et al., 2006), labile SOM fractions can be particularly important early indicators of the impact of management practices on soil health (Lefroy et al., 1993; Janzen et al., 1997; Haynes, 2005; Brady and Weil, 2007).

Particulate organic matter is operationally defined as the SOM associated with the sand-sized fraction and consists primarily of plant residue in initial stages of decomposition (Cambardella and Elliot, 1992; Potter and Derner, 2006). The POM fraction is a useful measure of labile SOM because sand-sized particles are enriched with plant polymers, while silt-sized particles are enriched with plant aromatics and clay-sized particles are enriched with recalcitrant microbial products (Christensen, 2001). Particulate organic matter typically makes up 20 to 45 percent of soil organic carbon (SOC) and 13 to 40 percent of N in soils (Cambardella and Elliot, 1992; Carter et al., 1994; Franzluebbers and Arshad, 1997). Particulate organic matter supplies most of the food for soil organisms, significantly affects nutrient cycling, and plays a key role in improving soil structure by promoting the formation and stabilization of macroaggregates (Puget et al., 1995; Wander, 2004; Haynes, 2005). Because soil microorganisms obtain cellular C and energy primarily from decomposition of POM, they generally colonize on and around the labile organic particles composing POM, and release microbial products (i.e., extracellular polysaccharides, glomalin, and hyphae) that physically bind soil particles together into aggregates, especially water-stable aggregates (Gregorich and Janzen, 1996; Hartel, 2005). Since POM is a transient SOM pool, continual crop residue inputs are essential to prevent these macroaggregates from breaking down (Haynes, 2005). Beneficial endogeic soil fauna, such as many types of earthworms and termites, also gain much of their food and energy from POM (Curry, 1998).

Furthermore, many studies have shown that labile SOM fractions such as POM are more sensitive to changes in management than is total SOM and often respond to management practices when changes in SOC are not detectable (Gregorich et al., 1994, 1997; Janzen et al., 1998; Campbell et al., 1999; Graham et al., 2002). Studies have shown that when changes in land use or management affect total SOM, accretion or depletion in SOM occurs primarily in POM (Carter et al., 2003). For example, Cambardella and Elliot (1992) demonstrated that SOC depletion in response to the conversion of native forest or prairie to cropland occurs disproportionately in the sand-sized POM fraction. Particulate organic matter has also been shown to be more sensitive than total SOM following a conversion from conventional tillage to conservation tillage (Franzluebbers and Arshad, 1997; Malhi et al., 2006), an increase in cropping intensity (Bowman et al., 1999), and a replacement of cereals or row crops with forage grasses (Doran et al., 1998; Franzluebbers et al., 2000). Other studies have revealed that management practices altering the amount or decomposition rate of crop residue disproportionately influence POM relative to total SOM (Doran et al., 1998; Bowman et al., 1999; Franzluebbers et al., 2000).

The effects of management practices on SOM depends on soil and climatic conditions, which vary by region (Ogle, 2005). Soils in the southeastern USA are generally low in SOM due to their mineralogy, a warm and humid climate that favors organic matter decomposition, and prior use of unsustainable management practices (Harden et al., 1999; Abrahamson et al., 2007). However, due to a favorable climate for productivity and the promising success of conservation tillage in the region, potential for SOM build-up is relatively high (Causarano et al., 2006). Given the relatively long growing seasons and plentiful rainfall in the region, a change in cropping system would be expected to increase SOM at a more rapid rate than in regions with shorter growing seasons and limited rainfall, such as the northern Great Plains (Halvorson et al., 2002; Sherrod et al., 2005). The southeastern United States has been identified as one of the most promising regions in North America for sequestering C by adopting conservation-oriented management practices (Franzluebbers and Steiner, 2002; Franzluebbers, 2005).

The ability of cropping systems to affect SOM and related soil properties varies due to differences among crop species in the amount and the biochemical composition, or quality, of the biomass produced (Wedin and Tilman, 1990; Drinkwater, 1998; Power et al., 1998; Hector et al. 2000; Martens, 2000a, 2000b). The impact of different crop species on SOM also depends on the physical characteristics of the biomass, including rooting patterns and activities (Cadisch and Giller, 1997). The accumulation of C in crop stalks and roots returned to the soil after harvest under no-till can contribute significantly to the sequestration of atmospheric CO_2 as stable SOM, which can help alleviate adverse effects of global warming (Lal, 2004). In humid subtropical environments, such as that of the southeastern United States, selecting crops to increase the amount of residue returned to the soil can compensate for rapid residue decomposition (Amado et al., 2006). Many studies of conservation tillage cropping systems have demonstrated a linear relationship between the amount of residue left after harvest and accretion or depletion of SOM (Black, 1973; Rasmussen and Collins, 1991; Trojan and Linden, 1994; Burle et al., 1997; Paul et al., 1997; Bayer et al., 2000; Franzluebbers, 2005; Malhi et al., 2006). Kong et al. (2005) reported that across 10 cropping systems under a Mediterranean climate there was a strong linear relationship between the quantity of crop residue returned to the soil and SOC sequestration. Ortega et al. (2002) verified the above relationship, concluding, "production of greater amounts of above- and belowground plant residues promoted by greater cropping intensity under no-till management can create higher levels of organic C and N in the surface soil." Trojan and Linden (1994) reported that under multiple tillage systems, cropping systems that produced more crop residue also accumulated SOM over the long term. In the Rothamsted experiment in England, Jenkinson and Johnson (1977) showed that crops producing greater amounts of residues supported significantly higher SOM levels. Griffin and Porter (2004) demonstrated that greater applications of organic soil amendments significantly increased total SOM, POM, and microbial biomass.

Optimal fertilizer inputs and other sound management practices contribute to SOM by producing greater amounts of crop residue (Moran et al., 2005). In addition to residue C, N inputs are also necessary for increasing SOM, chiefly because they enhance biomass production, and thus subsequent residue inputs. Drinkwater et al. (1998) ascertained that the added N from leguminous green manures significantly increased SOM-C and N. De Maria et al. (1999) concluded that inadequate external inputs of N were responsible for the lack of SOM accretion after nine years of no-till in Brazil. Moran et al. (2005) showed that fertilizer-N inputs facilitated the transformation of crop residue into stabilized SOM, and that inorganic and organic N inputs interact with one another to enhance their individual effects on SOM accumulation.

Though the addition of organic inputs contribute to labile SOM, more frequent residue inputs also stimulate microbial decomposition, a process called the “priming effect,” which results in a loss of labile SOM (Bell et al., 2003; Fontaine et al., 2004). Residue inputs increase the size of the microbial biomass and alter the microbial community structure with respect to the ratio of fungi to bacteria (F:B) (Bell et al., 2003). An increase in the F:B in soil encourages the cooperative decomposition of SOM, wherein fungi break down more recalcitrant C substrates, leaving more readily decomposable C compounds for decomposition by bacteria (Bottomley, 1999). Therefore, the priming effect is generally more intense in soils having a larger F:B (Bell et al., 2003). On the other hand, the increase in the F:B that typically occurs in response to conservation-oriented management practices such as no-tillage, crop rotations, and cover crops, can enhance the formation and protection of macroaggregates, leading to higher SOM accumulation (Simpson et al., 2004; Six et al., 2006)

Soil erosion is a key factor in the accretion and protection of SOM. Erosion preferentially removes soil enriched in SOM and disrupts soil aggregates, exposing more SOM to oxidation (Brady and Weil, 2007). Furthermore, the SOM removed by erosion is particularly high in biological activity because it is at or close to the surface. Approximately 20 percent of C detached and transported through erosion is released as CO_2 into the atmosphere and the rest is deposited in low-lying areas or carried into surface waters (Smith and Collins, 2007). In addition to direct effects on SOM, erosion downgrades many interactive physical, chemical, and biological properties of soils, including plant nutrient availability, aggregation, infiltration and soil water holding capacity, microbial activity and diversity, and soil depth (Pimentel et al., 1995; Pimentel and Kounang, 1998). The cumulative impact of these effects degrades soil health and hence reduces crop productivity. Accelerated soil erosion can cause a downward spiral in soil quality as the consequent reduced biomass production provides less vegetative cover and less organic inputs to SOM, increasing soil erosion and in turn, further reducing productivity (Brady and Weil, 2007). Erosion also causes many negative off-site effects, including siltation and eutrophication of surface waters, disruption of aquatic ecosystems, wildlife habitat loss, increased risk of flooding, air pollution, and an increase in the release of CO_2 into the atmosphere (Montgomery, 2007a). However, recent studies indicate that agricultural soil erosion constitutes an erosional C sink in some settings rather than a source of atmospheric C (Berhe et al., 2007; Van Oost et al., 2007).

Vegetative Cover and Soil Quality

Researchers estimate rates of soil erosion using the modeling or field measurement approaches. Soil erosion models such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) and the Revised Wind Erosion Equation (RWEQ) (Fryrear et al., 1998) can be useful for assessing erosion, but their accuracy is limited by high uncertainties and the lack of taking into account linkages and interactions between different erosion processes (Li et al., 2007). Erosion models that integrate data from small experimental plots can identify the key factors that regulate erosion processes and estimate erosion rates, though their results can be inaccurate (Kinnell, 2005) and difficult to extrapolate to lager spatial scales (Trimble and Crossan, 2000). Apart from modeling, soil erosion rates can be estimated by field measurements, such as with the cesium isotope (i.e., ^{137}Cs) technique (Li et al., 2007; Pennock, 2003). Researchers also use estimates of downstream sediment yield to evaluate soil erosion, but this method is complicated by the deposition of eroded soil in floodplains and other low-lying areas in proximity to agricultural fields (Montgomery, 2007b), and by the effects of damns (Syvitski et al., 2005). Sediment yields are generally much lower than the presumed erosion rates, indicating that a significant portion of eroded soil is transported downslope and stored nearby. Monitoring of erosion and resultant downstream sediment transport, blowing dust, or both can be important for evaluating the sustainability of different management practices like crop rotations and WCCs (Trimble and Crosson, 2000).

Human activities are responsible for the lowering the Earth's landscape by around 6 cm and for global erosion rates on agricultural land of around 75 Gt/yr (Wilkinson and McElroy, 2007). Pimentel and Skidmore (2004) estimated that erosion rates of United States cropland exceed rates of soil formation (~40 m/m.y.) by a factor of 12, indicating that the current state of U.S. agriculture is far from sustainable. Soil erosion rates vary by > 4 orders of magnitude, depending on environmental conditions regarding geology, soil properties, topography, vegetation, and rainfall amount and intensity (Montgomery, 2007b). For example, slope length and gradient strongly affect erosion rates, with the highest rates of erosion occurring on the landscape positions having the steepest slope gradients (Schumacher et al., 2005; Li et al., 2007). Slope length is a more important regulating factor than slope steepness on sites with high rill to interill erosion ratios, while slope steepness is more important on sites with low rill to interill erosion ratios. Row crop systems typically have moderate rill to interill erosion ratios. Another important regulating factor of soil erosion is the vegetative cover provided by different types of cropping systems (Brady and Weil, 2007).

The covering of soil by plant biomass, living or dead, protects the soil from erosion by wind and water (Pimentel and Kounang, 1998). The most effective way to control erosion is to implement management practices that increase vegetative cover (Pimentel et al., 1995). Vegetative cover has a strong influence on surface hydrology (Lopez-Bermudez et al., 1998; Glyssels, 2005; Vanacker et al., 2007). By absorbing the energy of wind shear, raindrop impact, and overland flow (Hillel, 1998; Steiner et al., 2000; Bruijnzeel, 2004), vegetative cover is critical in minimizing the negative effects of accelerated erosion on soil quality (Karlen et al., 1994b; Wildner, 2000; Erenstein, 2003; Dabney et al., 2004). Brady and Weil (2007) put forward that vegetative cover is "perhaps the most important requirement for maintaining and improving soil quality in intensive agroecosystems." In Utah and Montana, soil erosion increased by about 200 times as the vegetative cover decreased from 100 percent to less than 1 percent (Trimble and Mendel, 1995). Vanacker et al. (2007) demonstrated that increasing vegetation density reduced soil erosion to near natural benchmark levels in the southern Ecuadorian Andes.

The retention of crop residue on the surface in no-till systems is particularly effective in mitigating the loss of SOM by wind and water erosion (Amado et al., 2006; Krupinsky et al., 2007). A compilation of 39 studies comparing no-till and tillage-based management shows that no-till systems have soil erosion rates ranging from 2.5 to > 1,000 times lower and average 20 times lower (Montgomery, 2007b). For example, Truman et al. (2003) showed that compared to a tillage-based cotton system, a no-till cotton system had from two to nine times lower erosion rates in Alabama. Tillage-based systems result in erosion that is one to two orders of magnitude greater than rates of soil formation and natural soil erosion (Montgomery, 2007b).

Even small increases in vegetative cover can markedly reduce erosion and runoff (Lal, 2004; Pimentel, 2006), depending on rainfall, soil, topography, vegetation, and management factors (Brady and Weil, 2007). The relationship between vegetative cover and erosion has been demonstrated through the use of rainfall simulation and wind tunnel technology (Bilbro and Fryrear, 1994). Studies have shown that the application of straw mulch significantly reduces soil erosion (Barton et al., 2004). Commonly used soil erosion models integrate information regarding the relationship between erosion and vegetative cover and other erosion factors (Krupinsky et al., 2007). A compilation of many studies across a range of environmental conditions shows an exponential relationship between vegetative cover and interrill and rill erosion, relative to interill and rill erosion on bare soil (Glyssels, 2005; Vanacker et al., 2007). Vanacker et al. (2007) demonstrated an exponential decrease in sediment fluxes with increasing surface vegetative cover at the catchment scale. Research has also collectively shown that the detachment of soil by splash, relative to splash erosion on bare soil, decreases linearly and exponentially with increasing vegetative cover, depending on environmental factors (Glyssels et al., 2005). In general, soil erosion decreases dramatically from small increases in percent vegetative cover starting at 0 percent up to around 60 percent, above which decreases in erosion are relatively minor (Renard et al., 1997; Brady and Weil, 2007). In addition to aboveground plant biomass, roots play an important role in the soil's resistance to erosion, primarily by promoting aggregate stability, increasing water infiltration, and mechanically reinforcing the soil (Glyssels et al., 2005). The physical protection of the soil is extremely important in the southeastern United States, where soils are highly erodible, especially during high-energy rainstorms (Blevins et al., 1994). The maintenance of vegetative cover with crop residue around time of planting is crucial because the soil is most vulnerable to erosion during the seedling stage of crop growth, a period when there is no growing vegetation and rainfall is high (Unger, 1986).

Vegetative cover inhibits surface sealing, reduces the transport of soluble contaminants in surface runoff (Carter et al., 1994; Scopel et al., 2004), and improves water use efficiency (Karlen et al., 1994b; Lal, 1995; Ruan et al., 2001; Findeling et al., 2003). An increase in vegetative cover increases water infiltration, saturated hydraulic conductivity (Blanco-Canqui et al., 2007), soil water content (Nielsen, 2002), and reduces water loss by increasing snow-trapping (Ruan et al., 2001). Residue cover conserves soil water by reducing evaporation (Lal, 1995). In addition, vegetative cover can promote recovery from excessively dry and wet periods and extreme temperatures (Peterson et al., 1996), bring about favorable microclimate changes that encourage the growth of microarthropod populations (Badejo et al., 1995), and suppress weeds and soil-borne plant pathogens (Seguy et al., 2003; Bailey and Lazarovits, 2003; Lal, 2004; Donovan et al., 2006). Maintaining or increasing vegetative cover is also effective for buffering wheel traffic, alleviating problems associated with compaction, and increasing soil aggregation in no-till systems (Kumar and Goh, 2000; Blanco-Canqui and Lal, 2007).

It is well established that maintaining crop residues on the surface is an effective strategy for combating soil erosion (Duley and Russel, 1939; Matthews, 1945; Tanaka, 1986; Alberts and Neibling, 1994; Lal, 1995). A crucial management limitation in soil and water conservation can be inadequate residue cover (Cantero-Martinez et al., 2006). The proportion of the soil surface covered with crop residue occurs in an exponential relationship with the quantity of crop residue retained on the surface in no-till systems (Gregory, 1982). While the amount of crop residue needed for effective erosion control depends on climate and soil factors, the required amount of crop residue dry matter to cover close to 100 percent of the surface is about 8.1 to 13.4 Mg/ha (Mannering and Meyer, 1963; Lal, 1982; Roth et al., 1988). In southern Brazil, Roth et al. (1988) reported that the retention of 8.1 to 11.2 Mg/ha of soybean [*Glycine max* (L.) Merr.] or wheat (*Triticum aestivum* L.) residue dry matter on the surface was able to achieve 100 percent vegetative cover. Lal (1995) suggested around 2.5 to 4 Mg/ha following harvest as a minimum quantity for adequate erosion control.

For a given field or farm, the amount of crop residue on the surface depends on the amount of residue produced and its decomposition rate, which is determined primarily by the physical characteristics and biochemical composition, or quality, of the residue (Swift et al., 1979; Cadisch and Giller, 1997; Cantero-Martinez et al., 2006). Decomposition of plant residue left on the surface is greater as the initial N concentration increases and the C/N ratio narrows, which is chiefly dependent on crop species, stage of plant development when killed, and nutrient management

(Janzen and Kucey, 1988; Brady and Weil, 2007). Due to biological nitrogen fixation, legume residues contain considerable amounts of N and have a relatively low C/N residue, leading to more rapid decomposition than lower N-containing cereal residues (Janzen and Kucey, 1988). Nitrogen fertilization can increase the rate of residue decomposition and nutrient release by increasing the N concentration and decreasing the C/N ratio of the plant material (Ditsch et al., 1993; Janzen and Kucey, 1988; Grant et al., 2002). Under a sufficient N fertilization rate, the decomposition rates of a non-legume residue and a legume residue could be comparable (Grant et al., 2002). Greater N availability due to the release of N from decomposing legume residues can also decrease the C/N ratio of a subsequent non-legume (Stevenson and Van Kessel, 1996). In addition, plant biomass C/N ratio increases with phenological development, as the concentrations of lignin and cellulose increase and the concentration of protein decreases (Brady and Weil, 2007). Plants producing greater amounts of biomass often have higher C/N ratios, owed to an N diluting effect (Odhiambo and Bomke, 2001). Apart from the C/N ratio of plant materials, the measurement of lignin and polyphenolic contents is useful for assessing the influences of biochemical composition of plant tissues on residue decomposition rates (Cadisch and Giller, 1997). Decomposition rates decrease with increasing concentrations of lignin and polyphenolics (Cadisch and Giller, 1997, Brady and Weil, 2007). Physical attributes of crop residue, such as particle size, flatness, toughness, and capacity to absorb moisture, can be important factors in decomposition (Steiner et al., 1999, 2000; Zibilske and Materon, 2005).

Susceptibility to removal by wind, wind abrasion, fragmentation, and insect activity can also affect residue loss under no-till management (Stott et al., 1990). It has been suggested that more diverse cropping systems--producing residues with differing physical and biochemical attributes--are better able to supply N to growing crops while maintaining favorable levels of SOM (Sanchez et al., 2001).

Cropping systems vary widely in their ability to reduce erosion and runoff by maintaining vegetative cover (Brady and Weil, 2007). Cropping systems that use continuous monocultures of row crops and leave fields fallow between summer growing seasons provide low levels of vegetative cover and thus are more susceptible to erosion (Pimentel and Kounang, 1998). In no-till cropping systems, the selection of crops that produce higher quantities of biomass and biomass that is lower in quality (i.e., with slower decomposition rates) are more capable of maintaining adequate vegetative cover year-round (Villamil et al., 2006). Because plant residues with higher initial C/N ratios decompose more slowly, they provide full and thick vegetative cover for a longer time (Kumar and Goh, 2000). In Brazil, soybean residue had completely disappeared by the fourth month after the first rains of the wet season, while corn (*Zea mays* L.) and wheat residue still covered 20 to 30 percent of the surface into the fifth month (Bolliger et al., 2006). In addition, cropping systems with shorter fallow periods retain more crop residue on the surface (Halvorson et al., 2002). Even under no-till conditions, cropping systems that produce relatively low amounts of residue can be inadequate to protect the soil against erosion (Merrill et al., 2004; Wilhelm et al., 2004). For example, Merrill et al.

(2004) reported that subsequent to sunflower (*Helianthus annuus* L.) in a sunflower/spring wheat rotation under no-till in the northern Great Plains, a high-energy rainfall event caused substantial soil loss. Wilhelm et al. (2004) showed that a winter wheat/summer fallow system under no-till in the semi-arid western Great Plains provided only marginal vegetative cover for wind erosion control. Little research exists regarding the dynamics of crop residue quantity in long-term no-till cropping systems, especially in diverse cropping sequences (Cantero-Martinez et al., 2006). The tedious nature of residue sampling and processing involved in residue dynamics studies is likely one reason for this scarcity of information (Steiner et al., 1999).

Crop Rotations

The planned rotation of crops is an important conservation-oriented management practice used for improving soil productivity and long-term agricultural sustainability (Campbell et al., 1990; Bullock, 1992; Bolliger et al., 2006). Crop rotations can increase the potential yield of each crop in what is known as the "rotation effect" (Reeves, 1994, 1997; Porter et al., 1997; Anderson et al., 1999; Tanaka et al., 2005). Many studies have shown positive yield responses to the traditional rotation of corn with soybeans (Peterson and Varvel, 1989a, 1989b; Varvel, 1994b; West et al., 1996; Omay et al., 1998; Pikul et al., 2005). The ability of crop rotations to increase yields has been attributed to the disruption of weed, pest, and disease cycles (Noel and Wax, 2003; Anderson, 2005). In addition, improvements in soil health regarding erosion control (Darmody and Peck, 1997;

Wang et al., 2002), plant nutrient availability (Grant et al., 2002), SOM build-up (West and Post, 2002), available water (Larney and Lindwall, 1995), and biological activity and diversity (Kennedy, 1995; Beare et al., 1997; Karasawa et al., 2002) may be important factors in the rotation effect. The relationship between ecosystem functions or processes and the diversity of plant species is generally positive yet saturating, with different species uniquely affecting various processes (Hector and Bagchi, 2007). The inclusion of legumes in rotations with non-legumes can improve soil fertility (Campbell et al., 1990). The inclusion of crop species with deeper rooting depths in rotations with shallower rooting crops can recycle residual nutrients to the surface and break up compacted subsoil for the succeeding crop (Cresswell and Kirkegaard, 1995). Crop rotations, such as corn alternating with soybeans, commonly have significantly less risk of failing to meet an annual per hectare net return target, than continuous monoculture systems, due to diversification, reduced cost, and increased yields (Helmers et al., 2001). The strategic design of crop rotations has been an instrumental factor in agricultural economic competitiveness throughout the United States, such as in Southern cotton, West Coast horticulture, the Corn-Belt, and Great Plains grain production (Hennessy, 2006).

An increase in cropping sequence complexity can reduce fertilizer-N requirements by increasing the amount of readily mineralizable N (Sanchez et al., 2001; Drinkwater and Snapp, 2007). Rotating legumes with non-legumes increases N availability for the non-legume, reducing fertilizer-N requirements (Chalk, 1998;

Sanchez et al., 2001). Integrating leguminous crops such as soybean into rotations can enhance the release of N compounds by rhizodeposition, which can make up a significant portion of organic N additions (Chalk, 1998). While forage legumes such as alfalfa (*Medicago sativa* L.) are most effective at enhancing N availability for subsequent non-legumes, grain legumes such as soybeans can also contribute significant amounts of N. Ferreira et al. (2000) reported that the insertion of soybeans in rotation with non-legumes resulted in greater abundance and diversity of bradyrhizobia, which play a role in biological nitrogen fixation. In addition, rotating legumes with non-legumes can increase SOM compared to continuous monocropping of non-legumes (Gregorich et al., 2001).

In comparison to continuous monocultures of crops producing little residue, including high residue-producing or close-growing crops--such as corn or perennial grasses respectively--in rotations under no-till can be important in improving soil quality (Reeves, 1994; Bolliger et al., 2006; Katsvairo et al., 2006; Krupinsky et al., 2006, 2007; Merrill et al., 2006, 2007). In conservation tillage systems, crop productivity generally increases in response to crop rotations relative to continuous monocropping (Wilhelm and Wortmann, 2004). The inclusion of high residue-producing crops in rotations in no-till systems can reduce soil erosion (Pimentel, 2006), increase SOM (Seiter and Horwath, 2004), and as a result, improve many soil properties that are essential to sustainable crop productivity (Liebig et al., 2007). For example, Mitchell and Entry (1998) showed that cotton yield increased in a corn/cotton rotation relative to continuous cotton, and attributed this difference to the greater residue additions to SOM by corn. Soils in the southeastern United States managed through continuous monocropping of low residue-producing crops, such as cotton (*Gossypium hirsutum* L.) and soybeans, are particularly susceptible to erosion and depletion of SOM (Karlen et al., 1994a; Kirschenmann, 2002; Schwab et al., 2002).

Crop rotations can reduce erosion, primarily through increasing vegetative cover by rotating a high residue-producing crop with a low residue-producing crop (Liebig et al., 2007). Lacewall et al. (as cited by Reeves, 1997) reported that when compared to continuous monocropping of soybeans and sorghum [Sorghum bicolor (L.) Moench] under conservation tillage in Texas, including wheat in 2- or 3-year rotations with these crops significantly reduced wind erosion. Merrill et al. (2006) reported that under no-till, the high residue-producing wheat and flax crops (*Linum usitatissimum* L.) were needed in annual rotations with the low residue-producing crops sunflower and dry pea (*Pisum sativum* L.) in order to increase vegetative cover for adequate water and wind erosion control. Jankauskas and Jankauskiene (2003) observed that water erosion significantly decreased and soil aggregate stability significantly increased under different slope conditions when perennial grasses were included in rotations with grain crops in upland regions of Lithuania. Merrill et al. (2006) compared crop rotations involving 10 different crops under no-till in the northern Great Plains and concluded that crop rotations including the higher residue-producing crops wheat, barley (*Hordeum vulgare* L.), and flax maintained close to 100 percent vegetative cover. Crop rotations that included only lower residue-producing crops, such as dry bean (*Phaseolus vulgaris* L.) and safflower (*Carthamus tinctorius* L.), provided inadequate soil protection. Wang et al. (2002) maintained that expanding the use of the higher residue-producing crops corn, wheat, and sorghum and decreasing the use of the lower residue-producing crops potato (*Solanum tuberosum* L.) and pea significantly reduced wind erosion in Inner Mongolia, China. Gabriels et al. (2003) reported that increasing the frequency of corn in rotations significantly decreased the RUSLE C-factor, indicating greater soil protection by vegetative cover, and that the inclusion in rotations of the lower residue-producing winter cereals barley and wheat significantly increased the RUSLE C-factor. Krupinsky et al. (2007) showed that 2-year crop rotations composed of hard red spring wheat, proso millet (*Panicum miliaceum* L.), and grain sorghum had greater vegetative cover by crop residue than rotations of lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), and sunflower, an outcome which was attributed to differing quantities of residue produced by the two sets of crops.

Researchers recommend management practices that increase crop temporal diversity as means of increasing SOM, primarily because crop rotations often retain greater quantities of better-quality residue (Campbell et al., 1992; Biederbeck et al., 1994; Drinkwater, 1998; Havlin et al., 2005). Crop rotations that include high residue-producing crops (Havlin et al., 2005), pasture grasses (Franzluebbers et al., 2001; Franzluebbers, 2005), and legumes (Sainju et al., 2006), have been shown to increase SOM. For example, Acosta-Martinez et al. (2004a) discovered that an integrated crop-livestock system alternating perennial warm-season pasture of

‘W.W.B. Dahl’ old world bluestem (*Bothriochloa bladhii*) with cotton in West Texas had higher SOC, microbial biomass C, and enzyme activities, at 0 to 5 cm, than did continuous cotton. In a long-term experiment at the Morrow plots at the University of Illinois, Darmody and Peck (1997) showed that under different fertilization schemes, SOM levels were significantly lower under continuous corn than under corn rotated with oats and clovers. Because of low organic inputs, the continuous monoculture systems for many crops reduce SOM compared to rotations involving crops that produce higher amounts of organic residues (Acosta-Martinez et al., 2004a). The selection of high-input crops for inclusion in rotations increases the amount of residue returned to the soil and thus results in the build-up of SOM (Kumar and Goh, 2000). From a review of 20 studies in the southeastern United States, Causarano et al. (2006) concluded that rotating cotton with other crops, such as corn and small grains, results in significantly greater SOC sequestration than when cotton is grown year after year. Gregorich et al. (2001) reported that SOC derived from corn residues was much higher under a corn-legume rotation than when under continuous corn. Studdert and Echeverria (2000) demonstrated that increasing the frequency of higher aboveground residue-producing crops in rotations significantly increased SOM. Varvel (2006) reported that 2- and 4-year rotations in the Western Corn Belt substantially increased SOC after eight years when compared to continuous monocultures. Angers and Carter (1996) noted that crop rotations generally increase SOM, yet this effect depends on the type and quantity of crop residue returned to the soil. However, depending on crop species, the diversification of cropping systems through rotations can also change the quantity and quality of residues returned to the soil so that SOC decreases. For example, Acosta-Martinez et al. (2004b) reported that compared to continuous peanut (*Arachis hypogaea* L.), cotton-peanut rotations decreased SOC, microbial biomass C, and enzyme activities in West Texas.

Many studies have reported increased SOM in conservation tillage systems as high residue-producing crops are introduced into rotations with crops that produce relatively low amounts of residue, such as sod included in rotation with cotton and peanut (Katsvairo et al., 2006). In no-till systems, crop rotations that maximize the degree of crop residue retention on the surface are most effective in maintaining or increasing SOM (Bayer et al., 2000). Reeves (1997) reported that in tillage-based systems, 2- and 3-year rotations of cotton with corn and soybeans significantly increased SOM compared to continuous cotton. Acosta-Martinez et al. (2003) reported that in semiarid soils from West Texas under conservation tillage, alternating cotton with other crops, including sorghum, rye (*Secale cereale* L.), and wheat, generally increased soil enzyme activities at 0 to 5 cm, which was significantly correlated with SOC content. Abrahamson et al. (2007), using the Soil Conditioning Index, predicted that diverse crop rotations would significantly increase SOC compared to continuous cotton in no-till systems. In the Great Plains, no-till crop rotations that increased the amount of crop residue returned to the soil by reducing time under summer fallow, or increasing cropping intensity, resulted in higher SOM levels (Ortega et al., 2002). Malhi et al. (2006) reported that straw retention under both no-till and tillage-based systems increased total SOM as well as labile SOM fractions. Burle et al. (1997) showed that the quantity of residue retained in 10 no-till systems strongly influenced SOC at the 0 to 17.5 cm depth.

Apart from the direct effects on SOM and erosion, high-input crop rotations under no-till management can improve soil health by stimulating microbial and enzymatic activities in soils (Miller and Dick, 1995), encouraging earthworm burrowing and feeding activity (Bohlen et al., 1997; Blanco Canqui et al., 2007), and improving soil aggregation (Singh and Malhi et al., 2006). In addition, rotations that increase the amount of residue left on the surface in no-till systems can moderate fluctuations in soil temperature (NeSmith et al., 1987), increase the rate of N mineralization from organic residues (Grant et al., 2002), and conserve soil water (Tanaka and Anderson, 1997). Katsvairo and Cox (2000) showed that, in comparison to continuous corn, adopting New York corn rotations that included soybeans significantly increased profitability by reducing requirements for fertilizers, herbicides, and pesticides. In addition, under no-till management, increasing the amount of residue retained on the surface can reduce weed populations by smothering them, decreasing weed seed banks, creating less favorable conditions for seed germination, reducing N availability, and releasing allelopathic chemicals (Kumar and Goh, 2000; Caamal-Maldonado et al., 2001). Wicks et al. (1994) showed that increasing the amount of wheat residue retained after harvest significantly reduced the establishment of weed seedlings.

Given the economic advantage of growing the most profitable crops year after year, the potential short-term profitability of growing continuous monocultures of high-value crops can dissuade producers from adopting crop rotations (Reeves, 1994, 1997). Additionally, growing marketable crops that are well adapted to a particular soil and climate can reduce machinery costs, simplify management, favor specialization, and maximize profit potential. Scale economics in capital requirements may influence producers to choose continuous monoculture rather than crop rotations (Hennessy, 2006). In addition, producers may not wish to incur labor costs throughout the year, which is often necessary when crops are rotated (Reeves, 1994). Furthermore, in view of the present high degree of specialization of mechanized farming, producers may be unable to diversify cropping systems because of a lack of available equipment needed for specific crops (Personal communication, Forbes Walker, 2007).

Winter Cover Crops

The use of winter cover crops (WCC), as compared to winter fallow--in which nothing is planted so any vegetative growth consists of winter weeds--is another conservation-oriented management practice commonly integrated into no-till cropping systems to reduce erosion and enhance soil health in a variety of ways (Bolliger et al., 2006). Winter cover crops are close-growing crops grown primarily to protect the soil from erosion during the period between annual growing seasons (Brady and Weil, 2007). The widespread adoption of WCCs under no-till in Brazil has been cited as “probably the single most fundamental key to the success of such systems" (Derpsch, 2001; Steiner et al., 2001). Winter cover cropping can also increase SOM (Karlen and Cambardella, 1996; West and Post, 2002), scavenge residual nitrates before leaching moves them below the root zone (McCracken et al., 1994; Brandi-Dohrn et al., 1997), and supply additional N for the succeeding crops through biological nitrogen fixation in the case of leguminous WCCs (Hargrove, 1986; Kuo et al., 1997a, 1997b; Kuo and Jellum, 2000). Winter cover crops can encourage biological activity in soils (Boyer et al. 1999; Schutter et al., 2001), create root channels that alleviate the effects of compaction and allow for greater root growth of succeeding crops (Williams and Weil, 2004), suppress weeds (Teasdale, 1996; Fisk et al., 2001; Dhima et al., 2006), and conserve soil moisture (Teasdale and Mohler, 1993). Villamil et al. (2006) reported that hairy vetch (*Vicia villosa* Roth) and cereal rye as WCCs under no-till in Illinois improved various physical properties, including water aggregate stability, bulk density, penetration resistance, total and storage porosity, occluded pores, and plant-available water. If WCCs do not interfere with subsequent summer crops, their continued use can lead to increased yields (Brady and Weil, 2007). Many studies have shown that including WCCs in a cropping system can increase summer crop yields (Akanvou et al., 2000; Kuo and Jellum 2000; Reddy, 2001; Andraski and Bundy, 2005; Sainju et al., 2005; Snapp et al., 2005). Anyszka and Dobrzansk (2006) noted that rye and hairy vetch increased transplanted leek (*Allium porrum* L.) yields. Kumar et al. (2005) observed that the retention of hairy vetch residue on the surface improved tomato (*Lycopersicon esculentum* Mill.) yields and delayed leaf senescence in a greenhouse experiment. Entry et al. (1996) showed that long-term winter cover cropping in Alabama's "Old Rotation" experiment significantly increased total soil C and N, microbial biomass-C and N, and crop yields.

Many studies have established that, compared to winter fallow, the use of WCCs under no-till can significantly reduce erosion (Wendt and Burwell, 1985; Holderbaum et al., 1990; Mutchler and McDowell, 1990; Decker et al., 1994). Winter cover crops can help minimize soil erosion by providing additional vegetative cover during the non-growing season and surface residues following WCC termination, typically in late spring (Albert and Neibling, 1994; Kessavalou and Walters, 1999; Reinbott et al. 2004). Ruffo et al. (2004) reported greater residue coverage under a rye WCC than under winter fallow. In North Carolina, Creamer et al. (1997) demonstrated that 13 different WCCs and mixtures produced enough biomass three months after planting to maintain 100 percent vegetative cover. Nagumo et al. (2006) reported that, compared to winter fallow, the use of the WCC mucuna (*Mucuna* Adans.) in a no-till sorghum system significantly reduced soil erosion and runoff and increased water infiltration in Japan. Katsvairo et al. (2006) noted that the inclusion of the perennial grasses bahiagrass (*Paspalum notatum* Fluegge) and bermudagrass [*Cynodon dactylon* (L.) Pers.] as cover crops in a peanut-cotton rotation in Florida enhanced soil quality by reducing soil erosion. Kaspar et al. (2001) provided evidence that WCCs following soybeans increased vegetative cover and consequently reduced rill erosion. Paudel et al. (2006), in examining different residue management practices, demonstrated that the use of cover crops combined with poultry litter applications increased profitability of no-till cotton by reducing soil erosion. In a no-till corn system in Missouri, the inclusion of a wheat or rye WCC resulted in an annual soil loss of 0.9 Mg/ha compared to 22.0 Mg/ha under winter fallow (Wendt and Burwell, 1985). Mutchler and McDowell (1990) established a requirement for growing winter wheat or hairy vetch as WCCs under no-till continuous cotton in Mississippi in order to reduce soil erosion below tolerance levels. Compared to spring fallow, no-till spring cropping in eastern Washington significantly reduced susceptibility to wind erosion by increasing vegetative cover (Thorne et al., 2003).

The return of WCC biomass C and N to the soil increases SOM over the long term, thus improving the sustainability of cropping systems (McVay et al., 1989; Biederbeck et al., 1998; Kuo and Jellum, 2000; Sainju et al., 2002). Sainju et al. (2005) reported that SOC at 0 to 10 cm was significantly greater under the WCC hairy vetch with 0 kg N/ha compared to winter weeds with 0 and 60 kg N/ha in a no-till cotton/sorghum rotation in Georgia. Utomo et al. (1990) also reported an increase in SOC with hairy vetch under no-till relative to winter fallow. Studies in Brazil have revealed that the inclusion of nitrogen-fixing legumes such as hairy vetch, mucuna, and pigeonpea under no-till resulted in greater SOM accumulation (Sisti et al., 2004; Amado et al., 2006). Sainju et al. (2006) reported that in a no-till cotton/sorghum rotation in Georgia, hairy vetch and rye WCCs significantly increased SOC at 0 to 10 cm compared to winter fallow. In a no-till corn system in Brazil, Amado et al. (2006) found significantly higher SOC accumulation at 0 to 5 cm under the tropical leguminous cover crops velvet-bean (*Mucuna pruriens* (L.) DC.) and pigeon pea [*Cajanus cajan* (L.) Millsp.], compared to winter fallow. Katsvairo et al. (2006) reported that the inclusion of the perennial grasses bahiagrass and bermudagrass as cover crops in the peanut-cotton rotation in Florida enhanced soil quality by increasing SOM. Sainju et al. (2006) reported that rye, vetch, and a mixture of WCC residues contributed greater C inputs to SOC at 0 to 30 cm than did winter weeds in a no-till system in the southeastern United States. In reviewing studies of no-till cotton systems in the southeastern United States, Causarano et al. (2006) ascertained that cotton under conservation tillage with WCCs sequestered 0.67 ± 0.63 Mg C /(ha/yr), while with no WCC (i.e., winter fallow) it only sequestered 0.34 ± 0.47 Mg C /(ha/yr). Campbell et al. (2000) determined that reducing fallow frequency in Canada increased SOM. Griffin and Porter (2004) determined that while the WCC red clover had no significant effect on total SOM-C and N, it caused an increase in POM-N.

Winter cover crop root residue inputs increase SOM within the rooting zone below the upper few centimeters, which is particularly beneficial in no-till systems and in many fine-textured soils, where increases in SOM are primarily near the surface, to the detriment of SOM stored deeper in the soil profile (Wander et al., 1998; Kay and VandenBygaart, 2002). Villamil et al. (2006) reported that the use of the WCCs cereal rye and hairy vetch in a no-till corn/soybean rotation on a silt loam in Illinois with a 2 percent slope increased SOM at 0 to 5, 5 to 10, 10 to 15, and even down to 30 cm. In addition to increasing SOM by adding organic inputs, living WCC roots may decelerate SOM decomposition by reducing available nutrients for microorganisms, thereby reducing microbial abundance and decomposition (Cheng and Kuzyakov, 2005). Living WCC roots may also absorb SOM, thus making it temporarily unavailable for microbial decomposition (Sparling et al., 1982).

Conversely, other studies show no difference in SOM accrual between winter fallow and WCCs. Mendes et al. (1999) found no significant differences in SOC at 0 to 20 cm between winter fallow and the leguminous WCC red clover and the non-leguminous WCC triticale (×*Triticosecale* spp.) in a sweet corn/broccoli (*Brassica oleracea* L. var. *italica* Plenck) rotation in Oregon. Eckert (1991) reported that a rye WCC did not increase SOC under no-till in Ohio. Similarly, Shrestha et al. (2002) observed that cover crops used between the wet and dry seasons in rice (*Oryza sativa* L.) -based cropping systems in the Philippines did not significantly increase the carbon management index, and attributed this to the lack of a positive impact on total soil C.

In addition to the potential positive impacts on SOM, winter cover cropping generally benefits soil health through conserving and adding N (Seiter and Horwath, 2005). The additional N provided by leguminous WCCs can reduce commercial fertilizer-N requirements for optimal yields of the succeeding crop (Reeves, 1994, 1997; Sainju et al., 2007a). Kuo and Jellum (2000) reported that corn yields gradually increased during nine years of winter cover cropping with hairy vetch, cereal rye, and annual ryegrass (*Lolium multiflorum* Lam.), attributing this mainly to enhanced N availability. Reddy (2001) found higher soybean yields following rye than following winter fallow. Akanvou et al. (2000) reported that leguminous WCCs increased subsequent rice yields in comparison with winter fallow. The work of Sainju et al. (2005) revealed that under no-till, the WCCs rye and a rye-vetch mixture increased cotton yields in comparison to winter fallow. Leguminous WCCs such as vetch, clovers, and peas can sequester significant amounts of atmospheric N, (around 40 to 200 kg/ha) through biological N-fixation, reducing and possibly replacing inorganic fertilizer-N requirements, depending on the length of growth period and the amount of biomass produced (Hargrove 1986; Brady and Weil, 2007; Schomberg and Endale, 2004). Leguminous WCCs have been successfully adopted for enhanced N fertilization in many types of cropping systems, including cereals, small grains, pulses, vegetables, orchards, and gardens (Brady and Weil, 2007). Sainju et al. (2002) demonstrated that hairy vetch provided 50-120 kg N/ha for a subsequent tomato crop. Researchers at the University of Tennessee recommend the use of WCCs in no-till systems for soils in western Tennessee, since those soils are susceptible to erosion, runoff, and leaching of nutrients below the rooting zone, leading to contamination of surface water and groundwater (Cochran et al., 2007).

Winter cover crops differ a great deal among types and species in their effects on soil quality (Brady and Weil, 2007). Schomberg et al. (2006) established that the WCC rye produced 40 to 60 percent more biomass than black oat (*Avena* L.), oilseed radish (*Raphanus sativus* L.), and crimson clover (*Trifolium incarnatum* L.). In another example, hairy vetch and Austrian winter pea [*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir.] biomass contained greater than 80 kg N/ha more than did biomass of balansa clover [*Trifolium michelianum* Savi ssp. *balansae* (Boiss.) Ponert], crimson clover, oilseed radish, black oat, and rye (Schomberg et al., 2006). The same study also reported that the C/N ratio of the WCC rye was on average 39, while black oat, oilseed radish, and crimson clover C/N ratios were lower than 30, and consequently the N mineralization of rye residue was 20 to 50 percent slower than that of the other three WCCs. Ruffo et al. (2003) indicated that at termination time in a no-till corn system, rye and hairy vetch had significantly different biomass concentrations of neutral detergent fiber and acid detergent fiber, which were associated with the higher C/N ratio and slower residue decomposition of rye. In addition, rye and hairy vetch differed significantly in their quantities of biomass (Ruffo et al., 2003). Snapp et al. (2005) reviewed the literature on cover crops and noted that Brassica species cover crops are most effective at reducing pests and soil-borne diseases.

In addition, Snapp et al. (2005) found that non-legumes are more suited than legumes for establishing early and scavenging residual N, maximizing biomass production, and increasing SOM. Compared to leguminous cover crops, non-legumes or mixtures of non-legumes and legumes are generally more effective in scavenging residual nitrate (NO_3) N (McCraken et al., 1994) and in increasing SOM (Sainju et al., 2000). Primarily due to their more vigorous growth in the fall and more extensive root systems, non-legumes are more effective than legumes or winter weeds (i.e., under winter fallow) at reducing N leaching (Kuo et al., 1997b). Non-leguminous WCCs, such as winter wheat or cereal rye, generally produce more biomass than leguminous WCCs (Snapp et al., 2005). For example, compared to hairy vetch, the non-legumes cereal rye and annual ryegrass produced more biomass C and resulted in higher SOM-N (Kuo and Jellum, 2000). Because the higher N concentration and lower C/N ratios of legumes cause more rapid residue decomposition, the aboveground residue inputs from non-leguminous WCCs provide a more long-lasting groundcover than leguminous residues in no-till systems (Kuo et al., 1997).

On the other hand, leguminous WCCs, because they are able to fix atmospheric N in their tissues and typically have lower C/N ratios than non-leguminous WCCs, they can increase N availability for the succeeding crop as residue decomposes (Kuo and Jellum, 2002). For this reason, legumes are generally superior to other types of WCCs for increasing crop yields. Schomberg and Endale (2004) reported that residue decomposition rates, N mineralization rates, and N availability were higher following crimson clover than following cereal rye. Brown et al. (1985) showed that growing hairy vetch before cotton can significantly reduce N fertilizer requirements for optimal cotton yields in no-till systems. In addition to fixing N biologically, leguminous WCCs can improve the nitrogen use efficiency of subsequent crops by suppressing plant diseases and releasing growth-promoting substances from their decomposing residues (Stevenson and van Kessel, 1996). Nonetheless, Kuo and Jellum (2000) demonstrated that while the non-leguminous WCCs rye and annual ryegrass did not increase corn yields as immediately as hairy vetch, they still increased corn yields gradually over nine years. It is because of the distinct benefits of different types of WCCs that mixtures of WCC types (e.g. legume-cereal or Brassica-cereal) may be optimal when farmers have multiple goals (Snapp et al., 2005). Mixtures of leguminous and non-leguminous WCCs can be ideal for both adding N for the succeeding crop and reducing leaching of residual NO_3 below the root zone (Clark et al., 2007; Sainju et al., 2007a).

Winter cover crops reduce weed populations and herbicide requirements by competing with weeds for resources during the off-season and inhibiting weed emergence during the summer by adding to the surface residue layer (Khanh et al., 2005; Dhima et al., 2006). Studies have reported that WCCs reduce weeds during the summer growing season, leading to increased crop yields (Anyszka and Dobrzansk, 2006; Vasilakoglou et al., 2006). Anyszka and Dobrzansk (2006) showed that compared to winter fallow, the WCCs rye and hairy vetch reduced weed density in leek and enhanced leek growth, leaf chlorophyll content and area index, and yield. Vasilakoglou et al. (2006) noted that cereal WCC mulch suppressed grass weed abundance in cotton under Mediterranean conditions and increased cotton lint yield by up to 84 percent.

Although weeds growing together with main crops can lower crop yields through competition, annual winter weeds that germinate during the fall or early winter and mature during late spring or early summer can improve soil health (Zimdahl, 2007). Winter weeds can benefit a cropping system while reducing expenses by carrying out at no additional costs the same functions as WCCs, such as protecting the soil against erosion, scavenging residual $NO_{3,}$ and contributing to SOM

(Gliessman, 2006). Common winter weed species include Downy Brome (*Bromus tectorum* L.), Shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.], Pinnate Tansymustard [*Descurainia pinnata* (Walter) Britton], and Flixweed [*Descurainia sophia* (L.) Webb ex Prantl] (Zimdahl, 2007). Yuan et al. (2002) reported that the spontaneous growth of annual winter weeds as cover crops was more cost-effective in controlling sedimentation of the Mississippi Delta than were several best management practices; this practice reduced sediment yield by over 50 percent. Studies have also proven the capacity of native weeds to control pest insects (Landis et al., 2005) and favor beneficial insects (Altieri and Nicholls, 2004).

Potential deterrents to the adoption of WCCs in lieu of winter fallow include the cost of seed, management expenses, and the risk of main crop yield losses. Winter cover crops can reduce summer crop yields through competition, slow spring soil warming, or delayed planting (Nowak, 1992; Mitchell et al., 1999; Snapp et al., 2005). In addition, cover crop residues can potentially have negative allelopathic effects on summer crop yields. Li et al. (2005) showed that winter wheat inhibited subsequent crop growth through allelopathy.

Goals of this Study

There is a need for more information on the effects of crop rotations and WCCs on soil health under no-till in western Tennessee, particularly regarding the maintenance of vegetative cover and accrual of labile SOM. The purpose of the present study was to assess the abilities of different no-till cropping systems to carry out these functions in order to provide producers with the useful information for selecting management options that optimize agricultural sustainability. Our specific objectives were to evaluate the cumulative effects, after four to five years, on (i) surface residue quantity, (ii) aboveground WCC and winter weed biomass quantity (individually and combined) and quality, (iii) percent vegetative cover, and (iv) POM-C at 0 to 5 and 5 to 15 cm of the following practices:

1) inclusion of corn in rotations with cotton and soybeans, as in the cotton/soybeans/cotton/corn (Ct/S/Ct/C), cotton/corn (Ct/C), and corn/soybeans (C/S) rotations compared to the continuous monocropping of cotton (Ct) and soybeans (S)
2) the use of the WCCs winter wheat and hairy vetch compared to winter fallow
3) winter wheat compared to hairy vetch

We hypothesized that the inclusion of corn in rotations with cotton and soybeans and that winter cover cropping would both significantly increase surface residue quantity, aboveground plant biomass quantity, percent vegetative cover, and POM-C at 0 to 5 and 5 to 15 cm.

II. MATERIALS AND METHODS

Experimental Site

This field experiment was conducted at the Milan Research and Education Center in Gibson County, located in western Tennessee. This study was part of a long-term experiment initiated in 2002 at the site in order to evaluate the effects of different no-till cropping systems on SOC and other soil quality indicators. The predominant soil at this site has been mapped a Loring B2 silt loam, which belongs to the taxonomic class of fine-silty, mixed, active, thermic Oxyaquic Fragiudalf.

The experimental design was a randomized complete block strip-plot design with four replications. Main cropping sequences were comprised of continuous monocropping of cotton (Ct), corn (c), and soybeans (S), and of the cotton/soybeans/cotton/corn (Ct/S/Ct/C), cotton/corn (Ct/C), and corn/soybeans (C/S) rotations (the last abbreviation in a crop rotation designates the crop harvested in 2005). Winter treatments consisted of winter fallow and the WCCs winter wheat and hairy vetch. The plot size was 6.08 m × 13.68 m. Two buffer strips of the same width as the plots separate the field into three sections. The corn and soybeans were spaced 76.2 cm apart, while cotton row spacing was 101.6 cm.

Fertilizer-N rates were adjusted to provide the same levels of N among all the cropping sequences based on differences in the measured N contents of the aboveground biomass returned to the soil. During all years of the experiment from 2002 until 2006, 89.7 kg/ha of P_2O_5 and K_2O were applied as pre-plant to all treatments. Ammonium nitrate during all years was broadcast as pre-plant to cotton crops so that an estimated total of 101 kg N/ha was supplied. During all years, additional fertilizer-N in the form of urea ammonium nitrate was applied to corn crops as sidedress: 112.1 kg N/ha in 2002 and 2003, 156.9 kg N/ha in 2004, and 134.5 kg N/ha in 2005, and 112.1 kg N/ha in 2006. In 2002, ammonium nitrate was broadcast as pre-plant: 61.7 kg N/ha to cotton and corn crops with hairy vetch, 67.3 kg N/ha to corn crops with winter fallow and winter wheat, and 89.7 kg N/ha to cotton crops with winter fallow and winter wheat. In 2003, ammonium nitrate was broadcast as pre-plant: 61.55 kg N/ha to crops with winter fallow, 50.4 kg N/ha to crops with winter wheat, and 44.8 kg N/ha to crops with hairy vetch. In 2004, ammonium nitrate was broadcast: 67.3 kg N/ha as pre-plant to crops with winter fallow, 50.4 kg N/ha as pre-plant to crops with winter wheat and hairy vetch, and 33.6 kg N/ha as sidedress to cotton crops. In 2005 and 2006, ammonium nitrate was broadcast as pre-plant: 67.3 kg N/ha to crops with winter fallow plots and 50.4 kg N/ha to crops with winter wheat and hairy vetch.

Aboveground Crop Residue Quantity and Winter Cover Crop and Winter Weed Biomass Quantity and Quality

Aboveground crop residue, WCC biomass, and winter weed biomass were sampled in late spring 2006 and 2007, shortly before planting. Crop residue was also collected in December 2006. The aboveground WCC and winter weed biomass was collected by clipping just above ground level from one 0.5 m^2 quadrat in each plot. After aboveground plant biomass samples were taken, surface residue was collected by hand and with the aid of clippers, taking care not remove any root residue or crop residue covered by soil. Sampling locations within each plot were selected based on a visual estimation of a representative area with regard to residue and plant biomass abundance. Soil attached to plant biomass and residue was removed before processing to prevent its potential confounding effects on dry weights of plant material (Baumer and Bakermaus, 1973). Plant material samples were dried at 60^0 C, weighed, ground to < 1 mm, and thoroughly mixed. A dry combustion analyzer (Leco Corp, St. Joseph, MI) was used to measure the C and N contents of the plant material samples (Matejovic, 1997).

Percent Vegetative Cover

Percent vegetative cover refers to the percent of the soil covered by any living vegetation or senesced residue, including canopy vegetative cover and surface vegetative cover. Percent vegetative cover was measured in late spring 2006 and 2007 and in December 2006-07. In the field, percent vegetative cover was distinguished between residue, WCC biomass, and winter weed biomass, but overlapping of different types of plant materials confounds this approach. Because of this complicating factor, estimates of total percent vegetative cover without respect to the type of plant material were reported. Percent vegetative cover was estimated by the standard United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) technique for measuring crop residue cover, called the line-transect method, which involves looking directly downward and visually observing the presence of plant material at 100 points along a 15.2 m transect (Corak et al., 1993; Morrison et al., 1997). A measuring tape was placed diagonally across each plot twice and vegetative cover was recorded at 0.304 m intervals.

Particulate Organic Matter Carbon

In the late springs of both 2006 and 2007, eight soil cores were extracted with steel soil probes at random positions from each plot at the 0-5 and 5-15 cm depths after plant material was removed from the soil surface. Soil subsamples were then combined and mixed thoroughly to form a bulk sample. The samples were then allowed to air-dry at room temperature, ground with a mortar and pestle, and sieved to < 2 mm. Dry bulk density means of 1.41 Mg/ha at the 0 to 5 cm depth and 1.49 Mg/ha at the 5 to 15 cm soil depth, were previously determined with no significant variation among cropping treatments (Personal communication, Jason Wight, 2007).

Particulate organic matter carbon in these soil cores was fractionated according to the procedure described by Cambardella and Elliot (1992). First, 30 mL of 5 g/L sodium hexametaphosphate solution were added to 10 g of dry soil in small plastic bottles. The bottles were placed horizontally in a reciprocal shaker and shaken continuously for 16 h to disperse the soil particles. The soil solution was poured over a 53-μm sieve and rinsed thoroughly with distilled water to retain soil particles greater than 53 μm in diameter (i.e., sand-sized) (Christensen, 2001). The retained soil was rinsed into small aluminum trays, which were placed in an oven at 60^0 C. After approximately 36 hours of drying, soil samples were carefully removed from the trays, weighed, further ground with a mortar and pestle to < 1 mm, and thoroughly mixed before C analysis, again by dry combustion.

Statistical Analysis

The MIXED model analysis of variance (SAS Institute, Inc., Cary, NC) was used to analyze the strip-plot treatment design with summer cropping sequence and winter cover as the main effect factors. Least squares means were compared using Fisher's protected least significant difference at a 5 percent significance level.

III. RESULTS AND DISCUSSION

Aboveground Crop Residue Quantity

Continuous Cotton versus Cotton Rotations

In comparison to continuous cotton, the inclusion of corn in rotation with cotton significantly increased the amount of crop residue on the surface during the spring. In spring 2006, the mean measured aboveground crop residue quantity was significantly higher under the cotton-wheat/corn-wheat rotation than under continuous cotton-wheat (Table 1, Figure 1a). In winter 2006-07, there were no significant differences in the mean measured aboveground crop residue quantity between continuous cotton and the cotton rotations (Table 1, Figure 1b). In spring 2007, the mean measured aboveground crop residue quantities were significantly higher under the cotton-vetch/soybeans-vetch/cotton-vetch/corn-vetch and cotton-vetch/corn-vetch rotations than under continuous cotton-vetch (Table 1, Figure 1c). This increase in surface residue retention during the spring sampling periods under the cotton rotations, relative to under continuous cotton, is due to inclusion of corn as a high residue-producing crop in the rotations. It is important to note that increases in crop residue quantity under the cotton rotations occurred not only during the spring following the corn crop, but also during a subsequent spring following the low residue-producing cotton crop, which demonstrates a carryover effect of the corn residue. The absence of such an effect during the winter sampling period indicates that during the period between the winter and spring sampling

Table 1. Effects of cropping sequences on aboveground crop residue quantity

Treatments[#][^]	Crop residue dry weight (Mg/ha)		
	Spring 2006	Winter 2006-07	Spring 2007
Ct-S-Ct-C/Fallow	5.94 (1.49) ab	5.14 (1.18) bc	3.58 (3.02) cde
Ct-S-Ct-C/Wheat	5.04 (0.674) abcd	5.25 (3.14) bc	2.43 (0.796) defg
Ct-S-Ct-C/Vetch	4.06 (0.828) bcde	4.40 (1.26) bcde	3.46 (2.16) cde
Ct-C/Fallow	6.25 (0.293) a	5.24 (1.81) bc	4.69 (2.16) bc
Ct-C/Wheat	5.95 (1.80) ab	5.27 (0.614) bc	2.33 (0.919) efg
Ct-C/Vetch	4.22 (1.80) bcde	4.81 (1.54) bc	4.05 (1.62) cd
C-S/Fallow	3.11 (1.25) def	9.95 (1.63) a	6.12 (0.439) ab
C-S/Wheat	3.60 (1.05) def	8.55 (1.75) a	7.34 (0.947) a
C-S/Vetch	3.73 (2.36) cdef	9.17 (1.41) a	7.19 (0.851) a
Ct/Fallow	5.62 (1.22) abc	4.70 (1.10) bcd	2.91 (0.929) cdef
Ct/Wheat	3.48 (1.05) def	3.83 (0.998) cde	1.47 (0.038) g
Ct/Vetch	3.65 (0.933) cdef	5.28 (1.36) bc	0.981 (0.476) fg
C/Fallow	5.74 (1.37) ab	6.25 (0.328) b	7.92 (2.49) a
C/Wheat	6.64 (1.03) a	8.71 (1.25) a	6.53 (0.388) ab
C/Vetch	5.95 (2.94) ab	8.74 (0.801) a	6.47 (1.42) ab
S/Fallow	2.29 (1.19) ef	3.51 (0.307) cde	2.72 (0.701) defg
S/Wheat	2.06 (0.449) f	2.79 (0.435) de	2.76 (0.868) cdefg
S/Vetch	2.06 (1.05) f	2.74 (1.05) e	2.49 (0.770) defg
		P value	
Rotation	< 0.0001	< 0.0001	< 0.0001
WCC	0.1024	0.9466	0.1637
Rotation × WCC	0.3839	0.1050	0.0485
		Standard error	
	0.706	0.693	0.704

[#] Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

[^] Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability; Standard deviation is in parentheses.

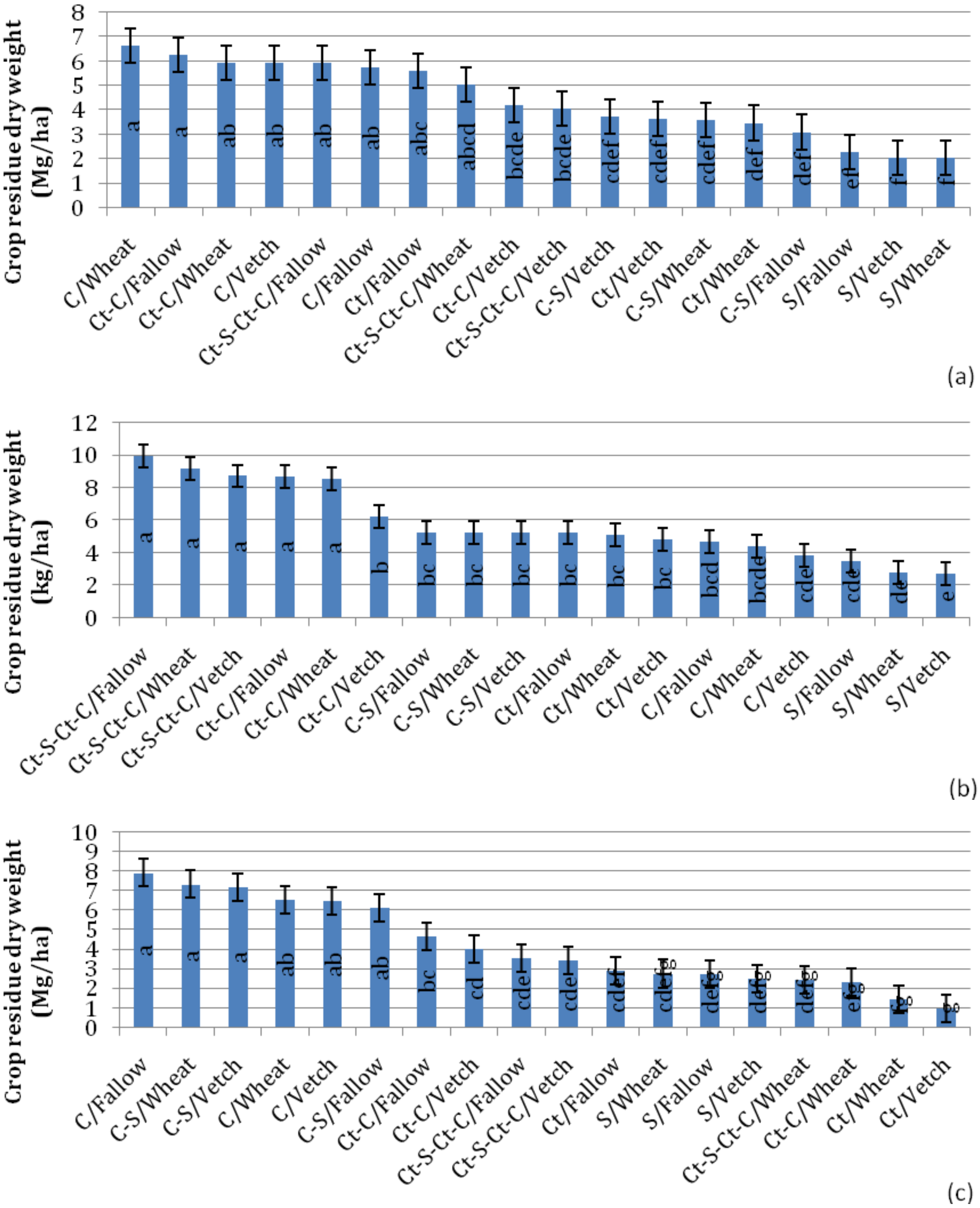

Figure 1. Differences in aboveground crop residue quantity among cropping sequences in (a) spring 2006, (b) winter 2006-07, and (c) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

periods, a greater proportion of the residue under continuous cotton decomposed relative to residue under the cotton rotations. The difference can be attributed to a greater resistance of corn residue to decomposition, given its particularly low quality and large particle size compared to cotton residue.

Continuous Soybeans versus Soybean Rotations

As with cotton, the inclusion of corn in rotation with soybeans significantly increased the amount of crop residue on the surface during the non-growing season, particularly in the spring. In spring 2006, the mean measured aboveground crop residue quantity was significantly higher under the cotton/soybeans/cotton/corn rotation than under continuous soybeans under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 1, Figure 1a). In winter 2006-07, the mean measured aboveground crop residue quantity was significantly higher under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat rotation than under continuous soybeans-wheat (Table 1, Figure 1b). In winter 2006-07 and spring 2007, the mean measured aboveground crop residue quantity was significantly higher under the corn/soybean rotation than under continuous soybeans under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 1, Figure 1b and c). A higher production of residue by corn as part of the soybean rotations likely caused these differences. The larger particle size of corn residue relative to finer soybean residue could be an important factor in the higher residue quantity under the soybean rotation compared to continuous soybeans (Cantero-Martinez, 2006). Significantly, the increase in residue quantity from the inclusion of corn occurred during the non-growing season following the corn crops, as well as during the subsequent spring, following the low residue-producing crops cotton and soybeans (i.e., a carryover effect). The above results are consistent with the conclusions of other studies that have also reported significant cropping systems effects on aboveground crop residue under no-tillage (Cantero-Martinez et al., 2006). These results correspond with those of Liebig and Varvel (2003), who found that the inclusion of corn into rotations with sorghum, soybeans, and an oat-clover mixture in Nebraska increased the production of crop residue, while the greater frequency of soybeans in rotations decreased the amount of residue.

Winter Fallow versus Winter Cover Crops

Compared to winter fallow, the WCCs generally did not affect the amount of residue retained on the surface, though the WCCs, especially winter wheat, significantly reduced the quantity of surface residue under some cropping sequences in the spring. In spring 2006, the mean measured aboveground crop residue quantity was significantly higher under the cotton-fallow/corn-fallow rotation than under the cotton-vetch/corn-vetch rotation (Table 1, Figure 1a). Also in spring 2006, the mean measured aboveground crop residue quantity was significantly higher under continuous cotton-fallow than under continuous cotton-wheat (Table 1, Figure 1a). In spring 2007, the mean measured aboveground crop residue quantity was significantly higher under winter fallow than under winter wheat in the cotton/corn rotation and continuous cotton (Table 1, Figure 1c). It is possible that the WCCs could have caused a priming effect on microbial activity, in which WCC inputs stimulate microbial biomass, enzymes, and activity, resulting in accelerated residue decomposition (Miller and Dick, 1995; Kuo et al., 1997; Schutter et al., 2001). Conversely, in winter 2006-07, the mean measured crop residue quantities were significantly higher under continuous corn-wheat and continuous corn-vetch than under continuous corn-fallow (Table 1, Figure 1b). These results differ from those of studies that have shown that more intensive no-till cropping systems retain larger quantities of crop residue on the surface because more crops are grown and there is less time under fallow (Cantero-Martinez et al., 2006; Sainju et al., 2006). However, the increase in aboveground crop residue quantity with the use of WCCs under continuous corn cannot be attributed to more WCC residue than winter weed residue remaining on the surface: by December the WCC and winter weed biomass from the previous winter were probably already completely decomposed. Ruffo and Bollero (2003) reported that at the end of the summer growing season of a no-till corn system, 100 percent of hairy vetch residue and 95 percent of rye residue had decomposed. The WCCs did not significantly reduce aboveground residue quantity in winter 2006-07 as they did in spring 2007, because they had more of a stimulatory effect on microbial decomposition of surface residue during the spring, when growth was more rapid and temperature increased.

Winter Wheat versus Hairy Vetch

This study found that the quantity of aboveground crop residue was generally insensitive to differences between the winter wheat and hairy vetch WCCs, excluding a significant difference in residue quantity under the cotton/corn rotation in spring 2007. In spring 2006 and winter 2006-07, there were no significant differences in the mean measured aboveground crop residue quantity between winter wheat and hairy vetch under all cropping sequences (Table 1, Figure 1a and b). These results are consistent with those of Miguez and Bollero (2006), who showed that the WCCs cereal rye and hairy vetch did not affect corn yields in a corn-soybean rotation in Illinois. In spring 2007, the mean measured aboveground crop residue quantity was significantly higher under the cotton-vetch/corn-vetch rotation than under the cotton-wheat/corn-wheat rotation (Table 1, Figure 1c).

Aboveground Winter Cover Crop and Winter Weed Biomass Quantity and Quality

Continuous Cotton versus Cotton Rotations

There were no significant differences in the mean measured aboveground WCC biomass quantity between continuous cotton and the cotton rotations under winter wheat and hairy vetch in spring 2006 and 2007 (Table 2, Figure 2a and b). This lack of difference suggests that aboveground WCC biomass production was insensitive to differences in the quantity and quality of the main crop residue inputs.

In comparison to continuous cotton, the inclusion of corn in rotation with cotton significantly increased the quantity of aboveground winter weed biomass. In spring 2006, the mean measured quantities of aboveground winter weed biomass were significantly higher under the cotton-fallow/soybeans-fallow/cotton-

Table 2. Effects of cropping sequences on aboveground winter cover crop and winter weed biomass quantity

Treatments[#][^]	Plant biomass dry weight (Mg/ha)					
	WCC	Winter weed	WCC + winter weed	WCC	Winter weed	WCC + winter weed
		Spring 2006			Spring 2007	
Ct-S-Ct-C/Fallow		1.15 (0.302) a	1.15 (0.302) abc		0.475 (0.101) def	0.475 (0.101) h
Ct-S-Ct-C/Wheat	0.660 (0.864) bcd	0.055 (0.0700) f	0.715 (0.111) cdef	0.359 (0.192) c	0.336 (0.313) efgh	0.696 (0.164) fgh
Ct-S-Ct-C/Vetch	0.645(0.224) bcd	0.430 (0.170) bcd	1.08 (0.273) abc	0.498 (0.238) c	0.432 (0.166) defg	0.929 (0.398) efg
Ct-C/Fallow		0.480 (0.117) bc	0.480 (0.117) fg		1.24 (0.282) a	1.24 (0.282) bcde
Ct-C/Wheat	0.470 (0.116) cd	0.125 (0.082) ef	0.595 (0.130) def	0.601 (0.263) bc	0.822 (0.264) bc	1.42 (0.107) bc
Ct-C/Vetch	0.520 (0.522) bcd	0.315 (0.318) bcdef	0.835 (0.508) bcdef	0.473 (0.146) c	1.08 (0.427) ab	1.55 (0.485) ab
C-S/Fallow		0.545 (0.115) b	0.545 (0.115) efg		0.883 (0.422) bc	0.883 (0.422) efg
C-S/Wheat	0.725 (0.381) bcd	0.080 (0.071) f	0.805 (0.324) bcdef	0.832 (0.297) b	0.0880 (0.039) hi	0.920 (0.313) efg
C-S/Vetch	0.795 (0.184) bcd	0.255 (0.148) bcdef	1.05 (0.195) abcd	0.538 (0.238) bc	1.32 (0.229) a	1.86 (0.282) a
Ct/Fallow		0.110 (0.123) f	0.110 (0.123) g		0.450 (0.179) defg	0.450 (0.179) h
Ct/Wheat	0.430 (0.931) d	0.020 (0.000) f	0.450 (0.0931) fg	0.369 (0.087) c	0.283 (0.0760) fghi	0.652 (0.130) gh
Ct/Vetch	0.610 (0.321) bcd	0.230 (0.238) cdef	0.840 (0.250) bcdef	0.477 (0.054) c	0.610 (0.112) cde	1.09 (0.137) cdef
C/Fallow		0.425 (0.082) bcde	0.425 (0.082) fg		0.653 (0.221) cd	0.653 (0.221) gh
C/Wheat	0.990 (0.862) abc	0.135 (0.145) def	1.13 (0.871) abc	0.824 (0.297) b	0.054 (0.034) i	0.877 (0.315) efg
C/Vetch	0.650 (0.159) bcd	0.215 (0.139) cdef	0.865 (0.025) bcdef	0.479 (0.141) c	0.655 (0.231) cd	1.13 (0.370) cde
S/Fallow		0.965 (0.644) a	0.965 (0.644) abcde		0.691 (0.0680) cd	0.691 (0.0680) gh
S/Wheat	1.35 (0.269) a	0.080 (0.071) f	1.43 (0.244) a	1.22 (0.122) a	0.145 (0.0110) ghi	1.37 (0.120) bcd
S/Vetch	0.945 (0.263) ab	0.300 (0.069) bcdef	1.25 (0.264) ab	0.566 (0.378) bc	0.411 (0.0270) defg	0.977 (0.374) defg
			P-value			
Rotation	< 0.0001	0.0003	< 0.0001	0.0012	< 0.0001	< 0.0001
WCC	0.1024	0.0005	0.0009	0.0046	0.0007	< 0.0001
Rotation × WCC	0.3839	0.0010	0.0731	0.0098	< 0.0001	0.0126
			Standard error			
	0.179	0.107	0.167	0.112	0.109	0.139

[#] Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

[^] Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability; Standard deviation is in parentheses.

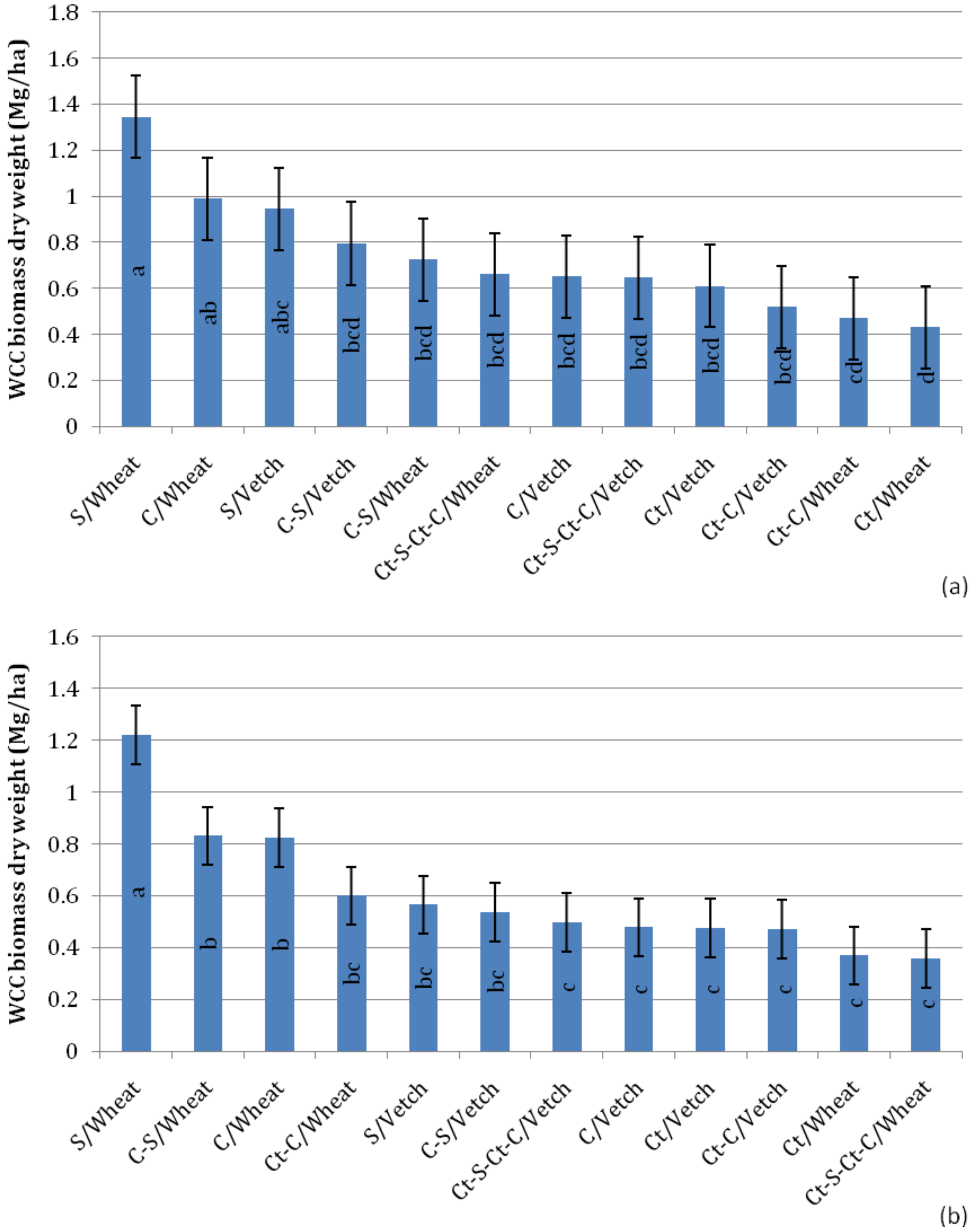

Figure 2. Differences in aboveground winter cover crop biomass quantity among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

fallow/corn- fallow and cotton-fallow/corn-fallow rotations than under continuous cotton-fallow (Table 2, Figure 3a). In spring 2007, the mean measured quantity of aboveground winter weed biomass was significantly higher under the cotton/corn rotation than under continuous cotton under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 2, Figure 3b). Corn residue added by the cotton/corn rotation, relative to only cotton residue added by continuous cotton, and could have encouraged winter weed growth compared to cotton residue by adding more residue to SOM (West and Post, 2002). Higher labile SOM levels could have improved aggregation, infiltration, and nutrient availability, potentially benefiting winter weeds (Cambardella and Elliot, 1992). Corn residue can also encourage winter weed growth by protecting the soil from erosion (Merrill et al., 2006), conserving soil moisture (Ruan et al., 2001), and moderating extremes in soil temperature.

Compared to continuous monocropping of cotton, the inclusion of corn in rotation with cotton significantly increased the total amount of aboveground plant biomass. In spring 2006, the mean measured aboveground WCC + winter weed biomass quantity was significantly higher under the cotton-fallow/soybeans-fallow/cotton-fallow/corn-fallow rotation than under continuous cotton-fallow (Table 2, Figure 4a). In spring 2007, the mean measured aboveground WCC + winter weed biomass quantity was significantly higher under the cotton/corn rotation than under continuous cotton under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 2, Figure 4b).

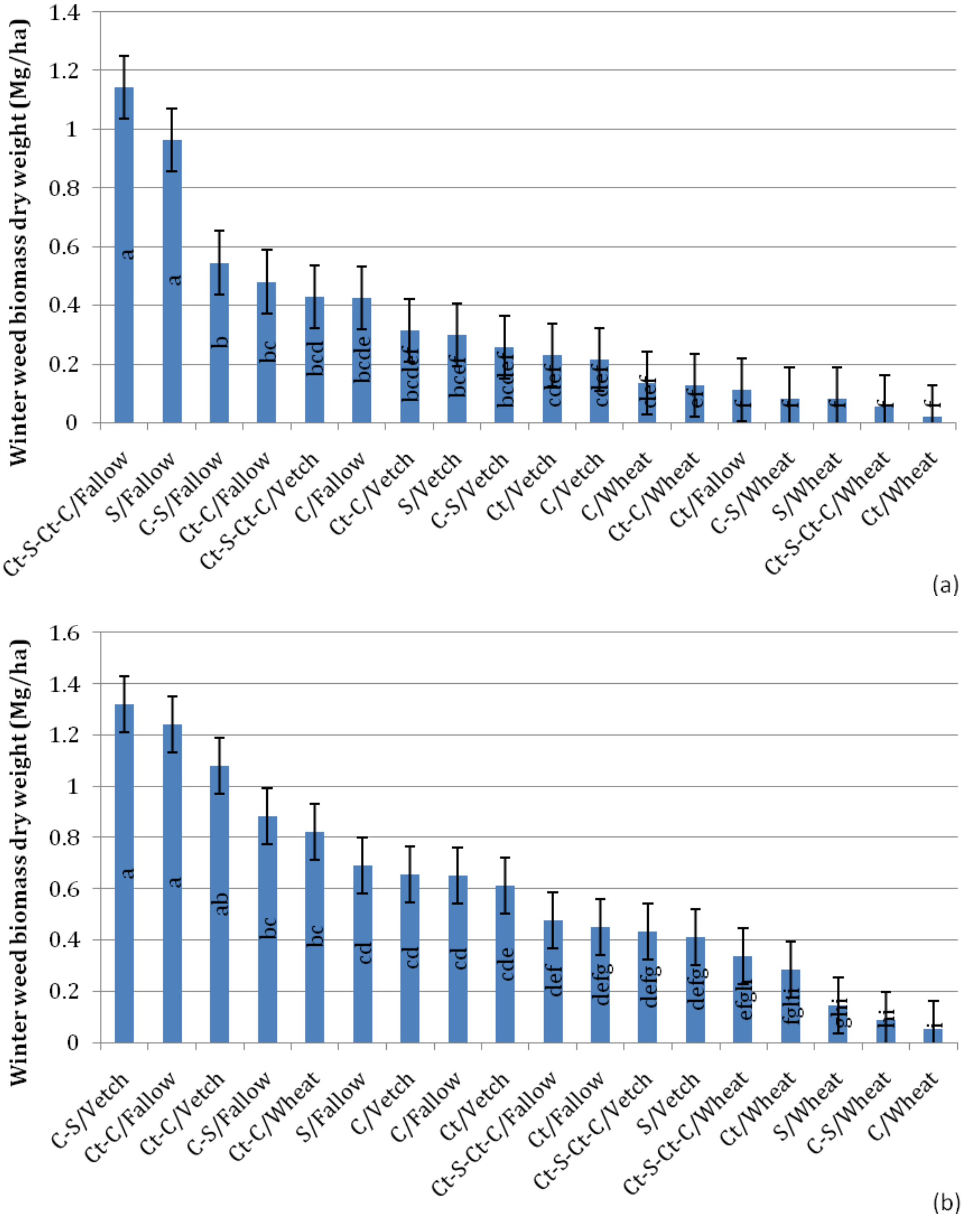

Figure 3. Differences in aboveground winter weed biomass quantity among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

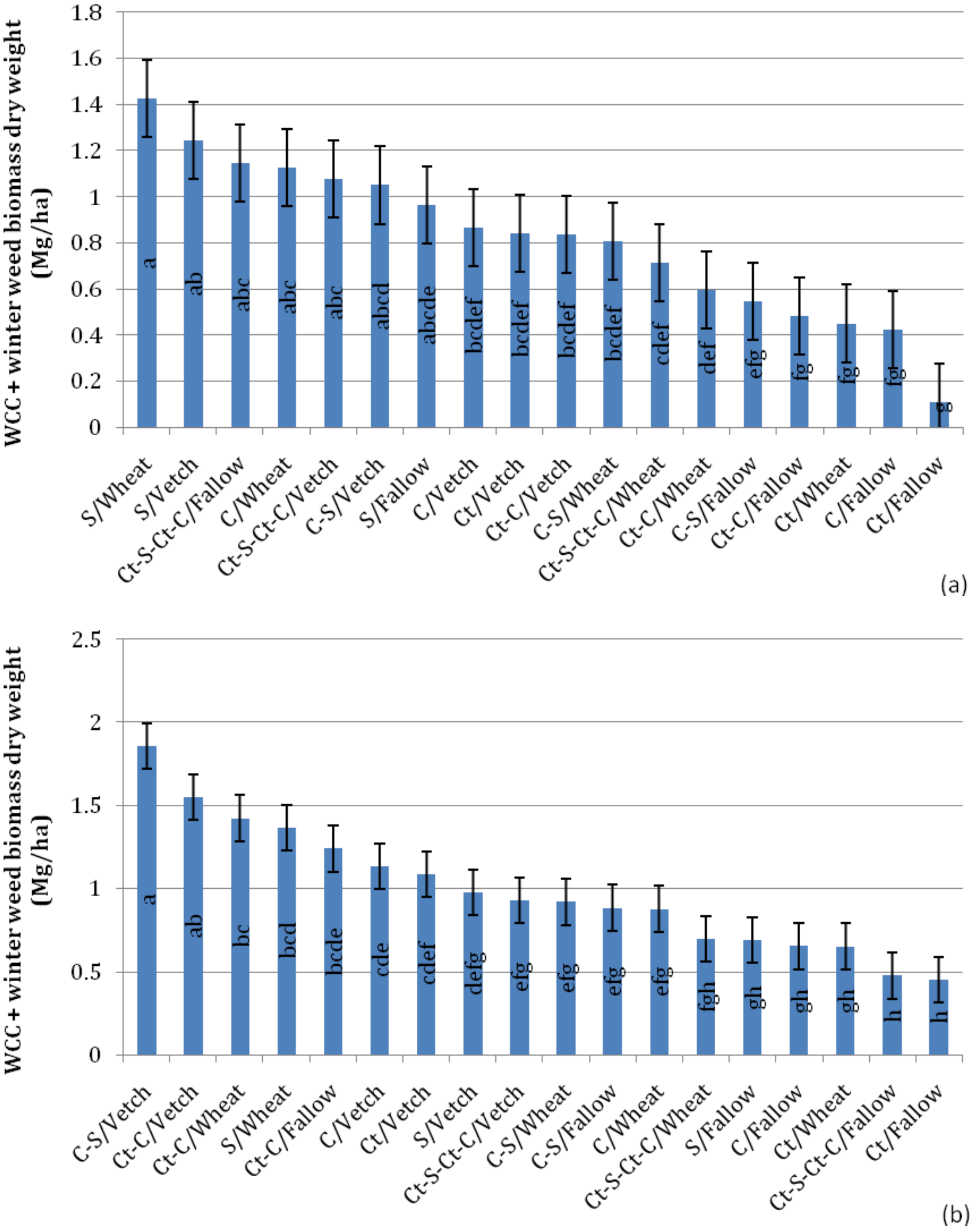

Figure 4. Differences in above ground winter cover crop biomass+ winter weed biomass quantity among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

There were significant differences in the aboveground WCC quality between continuous cotton and the cotton/corn rotation, but effects were contrasting in spring 2006 and 2007. In spring 2006, the mean measured aboveground WCC biomass C/N was significantly higher under the cotton-vetch/corn-vetch rotation than under continuous cotton-vetch (Table 3, Figure 5a). In spring 2007, the mean measured aboveground WCC biomass C/N ratio was significantly higher under continuous cotton-wheat than under the cotton-wheat/corn-wheat rotation (Table 3, Figure 5b).

In comparison to continuous cotton, the inclusion of corn in rotation with cotton significantly decreased the aboveground winter weed biomass C/N ratio, though this effect did not occur in spring 2006. In spring 2006, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat rotation than under continuous cotton-wheat (Table 3, Figure 6a). In spring 2007, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under continuous cotton than under cotton/corn under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 3, Figure 6b). Also in spring 2007, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under continuous cotton-fallow than under the cotton-fallow/soybeans-fallow/cotton-fallow/corn-fallow rotation (Table 3, Figure 6b).

Table 3. Effects of cropping sequences on aboveground winter cover crop and winter weed biomass quality

Treatments[#][^]	WCC biomass C/N ratio	Winter weed biomass C/N ratio	WCC biomass C/N ratio	Winter weed biomass C/N ratio
	Spring 2006		Spring 2007	
Ct-S-Ct-C/Fallow		32.3 (2.41) bcde		22.1 (3.12) cde
Ct-S-Ct-C/Wheat	31.3 (2.21) a	40.7 (4.67) a	22.7 (4.81) a	23.9 (6.85) abcd
Ct-S-Ct-C/Vetch	11.0 (0.311) c	28.9 (5.34) cdefg	10.9 (1.71) c	21.5 (2.65) cdef
Ct-C/Fallow		31.1 (3.03) bcdef		17.3 (1.43) fghi
Ct-C/Wheat	32.2 (3.35) a	33.7 (10.3) abcd	17.9 (1.72) b	19.3 (0.982) efgh
Ct-C/Vetch	21.2 (13.0) b	27.4 (3.53) cdefg	9.61 (0.373) c	17.5 (2.27) fghi
C-S/Fallow		32.2 (4.76) bcde		16.5 (0.818) ghi
C-S/Wheat	29.3 (5.62) a	32.7 (9.62) bcde	16.6 (4.18) b	16.6 (1.04) ghi
C-S/Vetch	10.3 (0.331) c	26.7 (5.60) defg	9.77 (0.992) c	15.6 (2.10) hi
Ct/Fallow		25.3 (4.97) efg		28.0 (1.55) ab
Ct/Wheat	30.9 (3.36) a	28.2 (5.35) cdefg	26.8 (6.25) a	28.2 (0.923) a
Ct/Vetch	10.1 (0.623) c	21.8 (2.02) fg	9.87 (0.273) c	25.1 (0.875) abc
C/Fallow		24.1 (3.84) g		14.1 (0.783) i
C/Wheat	28.4 (4.22) a	37.9 (1.80) ab	16.5 (1.14) b	20.1 (2.11) defg
C/Vetch	9.98 (0.363) c	27.8 (1.76) cdefg	10.0 (0.756) c	13.7 (1.64) i
S/Fallow		34.7 (7.23) abc		22.9 (1.58) cde
S/Wheat	33.2 (5.31) a	37.9 (6.24) ab	22.9 (5.00) a	23.6 (5.47) bcde
S/Vetch	11.8 (0.529) c	25.9 (3.69) efg	10.2 (1.42) c	23.2 (7.73) cde
			P-value	
Rotation	0.1320	0.0045	0.0048	< 0.0001
WCC	< 0.0001	0.0013	< 0.0001	0.0207
Rotation × WCC	0.1531	0.3372	0.0109	0.7013
			Standard error	
	2.41	2.67	1.55	1.59

[#] Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

[^] Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability; Standard deviation is in parentheses.

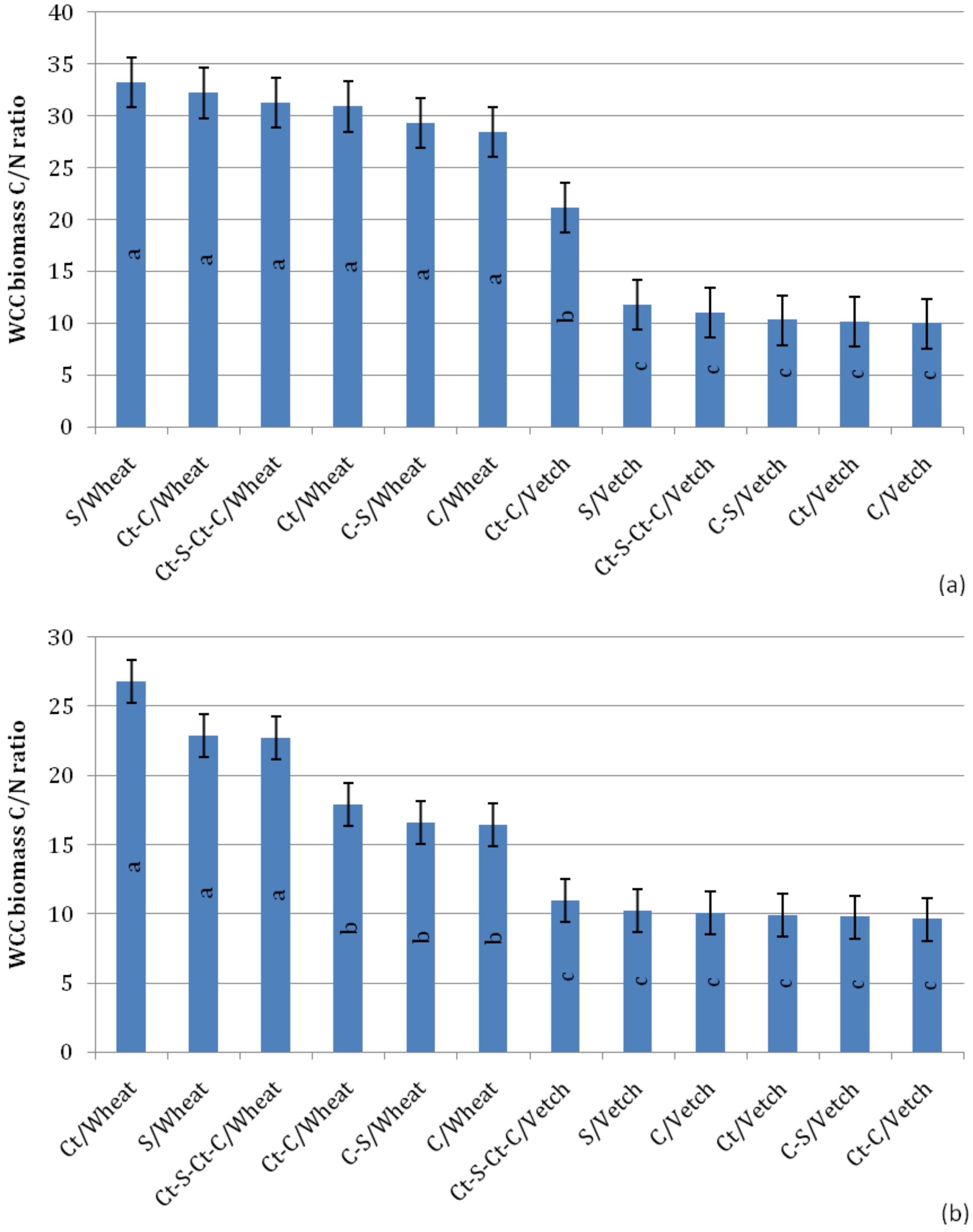

Figure 5. Differences in aboveground winter cover crop biomass quality among cropping sequences in (a) spring 2006 and (b) spring 2006. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

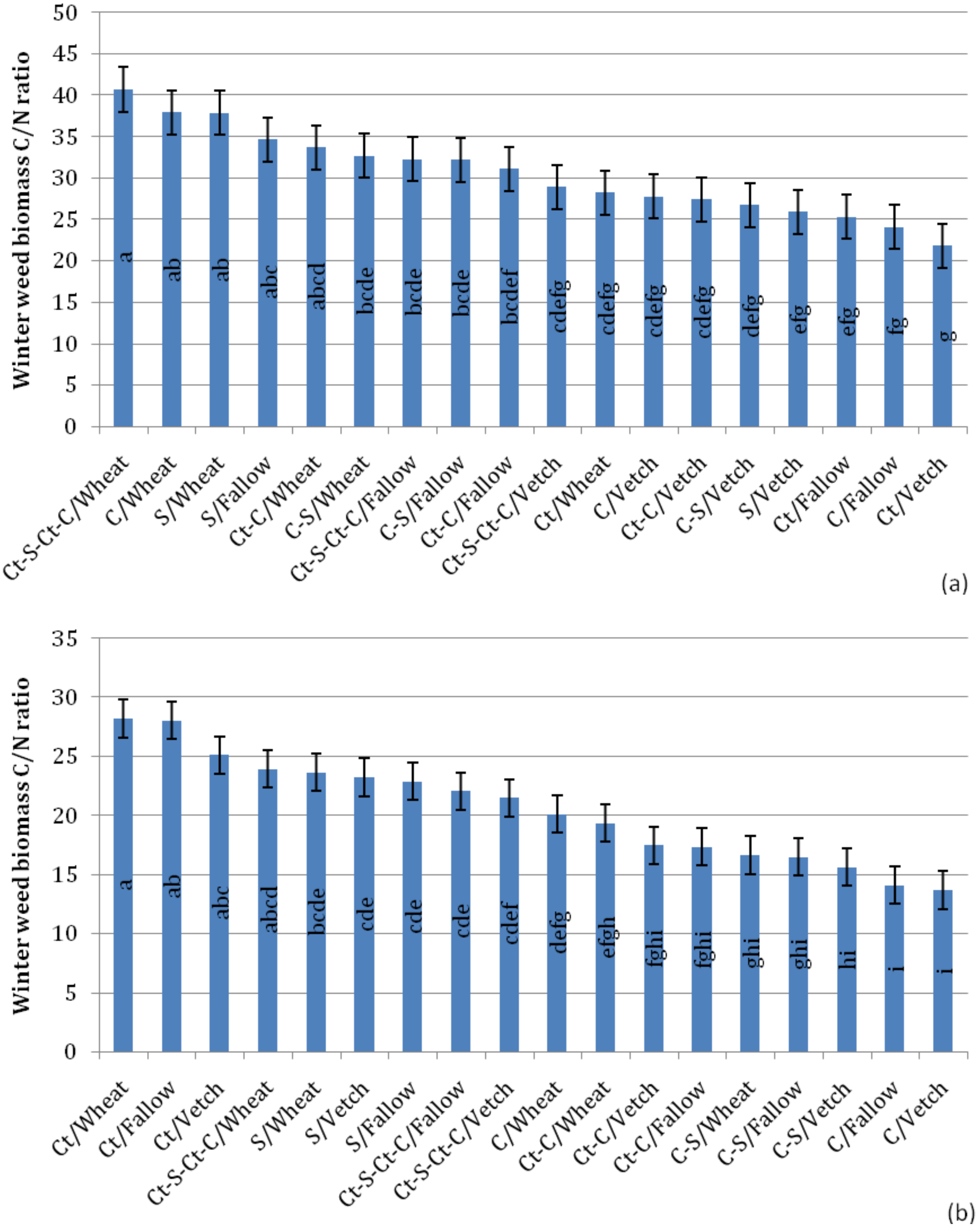

Figure 6. Differences in aboveground winter weed biomass quality among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

Continuous Soybeans versus Soybean Rotations

The aboveground WCC biomass quantity decreased significantly in response to the inclusion of corn in rotation with soybeans relative to continuous soybeans, though this effect occurred only under winter wheat and not under winter fallow and hairy vetch. In spring 2006 and 2007, the mean measured aboveground WCC biomass quantity was significantly higher under continuous soybeans-wheat than that under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat and corn-wheat/soybeans-wheat rotations (Table 2, Figure 2a and b).

Compared to the continuous monocropping of soybeans, the inclusion of corn in a 2-year rotation with soybeans significantly affected aboveground winter weed biomass quantity, though it had the opposite effect in spring 2006 and 2007. In spring 2006, the mean measured quantity of aboveground winter weed biomass was significantly higher under continuous soybeans-fallow than under the corn-fallow/soybeans-fallow rotation (Table 2, Figure 3a). In spring 2007, the mean measured quantity of aboveground winter weed biomass was significantly higher under the corn-vetch/soybeans-vetch rotation than under continuous soybeans-vetch (Table 2, Figure 3b).

In comparison to continuous soybeans, the inclusion of corn in rotation with soybeans consistently and significantly decreased the amount of total aboveground plant biomass in the spring under winter wheat, though the opposite effect occurred under hairy vetch in 2007. In spring 2006 and 2007, the mean measured aboveground WCC + winter weed biomass quantity was significantly higher under continuous soybeans-wheat than under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat and corn-wheat/soybeans-wheat rotations (Table 2, Figure 4a and b). Additionally, in spring 2007, the mean measured aboveground WCC + winter weed biomass quantity was significantly higher under the corn-vetch/soybeans-vetch rotation than under continuous soybeans-vetch (Table 2, Figure 4b).

In comparison to continuous soybeans, the inclusion of corn in rotation with soybeans generally did not significantly affect aboveground WCC biomass C/N ratio, with the exception of a significant difference between continuous soybeans and the corn/soybean rotation in spring 2007. In spring 2006, there were no significant differences in the mean measured aboveground WCC biomass C/N ratio between continuous soybeans and the soybean rotations (Table 3, Figure 5a). In spring 2007, the mean measured aboveground WCC biomass C/N ratio was significantly higher under continuous soybeans-wheat than under the corn-wheat/soybeans-wheat rotation (Table 3, Figure 5b). While annual legume residues mineralize rapidly and can supply more N to subsequent cereal crops than cereal residues (Yamoah et al., 1998; Grant et al., 2002), levels of residual fertilizer-N, which may differ among cropping sequences, influence the availability of N for WCCs and consequently their C/N ratios. Higher residual fertilizer-N following corn as opposed to following soybeans can decrease the C/N ratio of the subsequent winter wheat cover crop (Personal communication, Forbes Walker, 2007).

Compared to the continuous monoculture of soybeans, including of corn in a 2-year rotation with soybeans significantly reduced the aboveground winter weed biomass C/N ratio following the corn crop, though this effect did not occur in spring 2006. In spring 2006, there were no significant differences in the mean measured aboveground winter weed biomass C/N ratio between continuous soybeans and the soybean rotations (Table 3, Figure 6a). In spring 2007, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under continuous soybeans than under the corn-soybean rotation under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 3, Figure 6b). As with the winter wheat C/N ratio, it is possible that greater residual nitrogen following the corn crop of the corn-soybean rotation also lowered the winter weed C/N ratio.

Winter Fallow versus Winter Cover Crops

Compared to winter fallow, the WCCs winter wheat and hairy vetch, especially winter wheat, generally reduced the amount of aboveground winter weed biomass. In spring 2006, the mean measured quantity of aboveground winter weed biomass was significantly greater under winter fallow than under winter wheat in the cotton/soybeans/cotton/corn, cotton/corn, and corn/soybean rotations, and continuous soybeans (Table 2, Figure 3a). Also in spring 2006, the mean measured aboveground quantity of winter weed biomass was significantly greater under winter fallow than under hairy vetch in the cotton/soybeans/cotton/corn rotation and continuous soybeans (Table 2, Figure 3a). In spring 2007, the mean measured quantity of aboveground winter weed biomass was significantly greater under winter fallow than under winter wheat using the cotton/corn and corn/soybean rotations, continuous corn, and continuous soybeans (Table 2, Figure 3b). Also in spring 2007, the mean measured quantity of aboveground winter weed biomass was significantly greater under the corn-vetch/soybeans-vetch rotation than under the corn-fallow/soybeans-fallow rotation (Table 2, Figure 3b). The reduced winter weed biomass under WCCs can be attributed to increased competitive pressure on resources such as water, nutrients, and sunlight, changes in soil temperature, and the potential release of toxic allelopathic chemicals (Conklin et al. 2002; Creamer et al., 1996; Teasdale, 1996; Tilman et al., 2001). Our results are consistent with those of Moynihan et al. (1996), who demonstrated that growing annual medics as WCCs reduced winter weed biomass by 65 percent. Similarly, Fisk et al. (2001) reported that the leguminous WCCs red clover and annual medics reduced winter and summer weed biomass dry weight under no-till corn. There are very few studies in the scientific literature examining how cropping systems affects winter weeds. Future research could evaluate the potential of annual winter weeds to control erosion.

The use of WCCs significantly increased the quantity of total aboveground biomass (WCCs + winter weeds) relative to winter fallow in a few cropping sequences, though in most cropping sequences winter fallow plots had as much or more total aboveground plant biomass as plots with WCCs. In spring 2006, the mean measured total aboveground biomass quantity was significantly higher under continuous corn-wheat than under continuous corn-fallow (Table 2, Figure 4a). Also in spring 2006, the mean measured quantity of total aboveground biomass was significantly higher under hairy vetch than under winter fallow in the corn/soybean rotation and continuous cotton (Table 2, Figure 4a). In spring 2007, the mean measured quantity of total aboveground biomass was significantly higher under continuous soybeans-wheat than under continuous soybeans-fallow (Table 2, Figure 4b). At the same time, the mean measured quantity of total aboveground biomass was significantly higher under hairy vetch than under winter fallow in the cotton/soybeans/cotton/corn and corn/soybean rotations, continuous cotton, and continuous corn (Table 2, Figure 4b).

Compared to winter fallow, WCCs generally did not significantly influence the quality of aboveground winter weed biomass, with a few exceptions indicating higher winter weed biomass C/N ratios with winter wheat and lower weed C/N ratios with hairy vetch. In spring 2006, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under winter wheat than under winter fallow in the cotton/soybeans/cotton/corn rotation and continuous corn (Table 3, Figure 6a). Also in spring 2006, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under continuous soybeans-fallow than under continuous soybeans-vetch (Table 3, Figure 6a). In spring 2007, the mean measured aboveground winter weed biomass C/N ratio was significantly higher under continuous corn-wheat than under continuous corn-fallow (Table 3, Figure 6b).

Winter Wheat versus Hairy Vetch

The WCCs winter wheat and hairy vetch generally produced comparable amounts of aboveground biomass, though winter wheat produced more biomass than hairy vetch under continuous corn during one of two spring sampling periods. In spring 2006, there were no significant differences in the mean measured aboveground WCC biomass quantity between winter wheat and hairy vetch under all cropping sequences (Table 2, Figure 2a). In spring 2007, the mean measured aboveground WCC biomass quantity was significantly higher under continuous corn-wheat than under continuous corn-vetch (Table 2, Figure 2b).

Annual winter weed growth was greater under hairy vetch than under winter wheat. In spring 2006, the mean measured quantity of aboveground winter weed biomass was significantly greater under the cotton-vetch/soybeans-vetch/cotton-vetch/corn-vetch rotation than under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat rotation (Table 2, Figure 3a). In spring 2007, the mean measured quantity of aboveground winter weed biomass was significantly higher under hairy vetch than under winter wheat under the corn/soybean rotation, continuous cotton, and continuous corn (Table 2, Figure 3b).

The quantities of total aboveground biomass (WCCs + winter weeds) produced in the spring under winter wheat and hairy vetch was generally comparable, with the exception of more total aboveground biomass with hairy vetch than with winter wheat under two cropping sequences in spring 2007. In spring 2006, there were no significant differences in the mean measured total aboveground biomass quantity between winter wheat and hairy vetch under all cropping sequences (Table 2, Figure 4a). In spring 2007, the mean measured quantity of total aboveground biomass quantity was significantly higher under hairy vetch than under winter wheat under the corn/soybean rotation and continuous cotton (Table 2, Figure 4b).

In spring 2006 and 2007, the mean measured aboveground winter wheat biomass C/N ratio was significantly higher than that of hairy vetch under all cropping sequences (Table 3, Figure 5a and b). This reflects biological fixation of atmospheric nitrogen by hairy vetch. The differences in C/N ratio that were observed between winter wheat and hairy vetch are consistent with those reported elsewhere (Kuo et al., 1996; Clark et al., 1997; Odhiambo and Bomke, 2001; Ruffo et al., 2003; Schomberg et al., 2006). The current study supports the work of Clark et al. (1997), which reported C/N ratios of hairy vetch biomass during the spring in Maryland ranging from 9/1 to 11/1. The higher biomass C/N ratio of winter wheat indicates that it has a slower rate of decomposition and can potentially provide better soil protection as surface residue during the early growth stages of the succeeding crop (Cadisch and Giller, 1997). Ruffo and Bollero (2003) also compared the residue quality of a leguminous and a non-leguminous WCCs and associated effects on soil quality under no-till management. They reported that the WCCs rye and hairy vetch used in a no-till corn system differed significantly in their N contents and N and C mineralization rates. Considering the practical implications of their results, Ruffo and Bollero (2003) concluded, "Decomposition dynamics of hairy vetch residue indicate that it is a potential source of N while decomposition dynamics of rye indicate that it is more useful in soil conservation."

These results also show that, compared to winter wheat, hairy vetch significantly reduced the C/N ratio of aboveground winter weed biomass, although this effect did not occur under most cropping sequences in spring 2007. In spring 2006, the mean measured winter weed biomass C/N ratio was significantly higher under winter wheat than under hairy vetch in the cotton/soybeans/cotton/corn rotation, continuous corn, and continuous soybeans (Table 3, Figure 6a). In spring 2007, the mean measured winter weed biomass C/N ratio was significantly higher under continuous corn-wheat than under continuous corn-vetch (Table 3, Figure 6b).

Percent Vegetative Cover

We observed a very high percentage of vegetative cover under each cropping sequence, even those with continuous monoculture of the relatively low residue-producing main crops cotton and soybeans and without WCCs (i.e., winter fallow) (Table 4, Figure 7). Only three cropping sequences in spring 2006 had a percent vegetative cover below 90 percent, while all cropping sequences provided greater than 90 percent vegetative cover during winter 2006-07 and spring 2007. Across all sampling periods and cropping sequences, percent vegetative cover ranged from 75 to 100 percent, and averaged 96 percent. Near complete vegetative cover can be attributed to the high biomass production characteristic of warm and

Table 4. Effects of cropping sequences on percent vegetative cover

Treatment[#^]		Percent vegetative cover	
	Spring 2006	Winter 2006-07	Spring 2007
Ct-S-Ct-C/Fallow	97.5 (1.73) abcd	98.5 (1.73) ab	98.5 (1.91) ab
Ct-S-Ct-C/Wheat	92.0 (8.87) cde	95.0 (3.56) abcde	98.3 (3.50) ab
Ct-S-Ct-C/Vetch	96.3 (2.87) abcd	93.0 (4.32) e	98.0 (1.63) ab
Ct-C/Fallow	98.3 (0.957) abc	94.3 (4.99) bcde	98.5 (1.91) ab
Ct-C/Wheat	98.0 (1.41) abc	95.5 (1.91) abcde	98.0 (1.63) ab
Ct-C/Vetch	99.3 (0.957) a	93.3 (2.50) cef	99.0 (2.00) ab
C-S/Fallow	98.8 (0.500) a	97.0 (3.46) abcde	100 (0.00) ab
C-S/Wheat	92.8 (5.25) bcd	98.3 (1.26) abc	100 (0.00) a
C-S/Vetch	98.8 (1.89) ab	98.3 (2.36) abc	100 (0.00) ab
Ct/Fallow	75.3 (7.04) g	94.5 (2.65) bcde	98.0 (1.63) ab
Ct/Wheat	85.3 (7.54) f	93.3 (6.24) def	92.3 (4.19) c
Ct/Vetch	85.8 (2.06) ef	92.5 (3.32) e	98.0 (1.63) ab
C/Fallow	93.5 (7.19) abcd	99.5 (1.00) a	99.5 (1.00) ab
C/Wheat	95.3 (7.19) abcd	98.8 (1.50) ab	99.5 (1.00) ab
C/Vetch	93.0 (6.48) abcd	94.0 (7.35) bcde	99.5 (1.00) ab
S/Fallow	96.8 (2.99) abcd	96.3 (2.87) abcde	99.5 (1.00) ab
S/Wheat	91.0 (3.16) def	93.3 (4.11) def	97.5 (1.00) ab
S/Vetch	97.8 (3.30) abc	93.3 (2.36) cef	99.5 (1.00) ab
		P value	
Rotation	< 0.0001	0.0100	< 0.0001
WCC	0.1255	0.2097	0.0641
Rotation × WCC	0.0141	0.5942	0.0279
		Standard error	
	2.31	1.80	0.896

[#] Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

[^] Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability; Standard deviation is in parentheses.

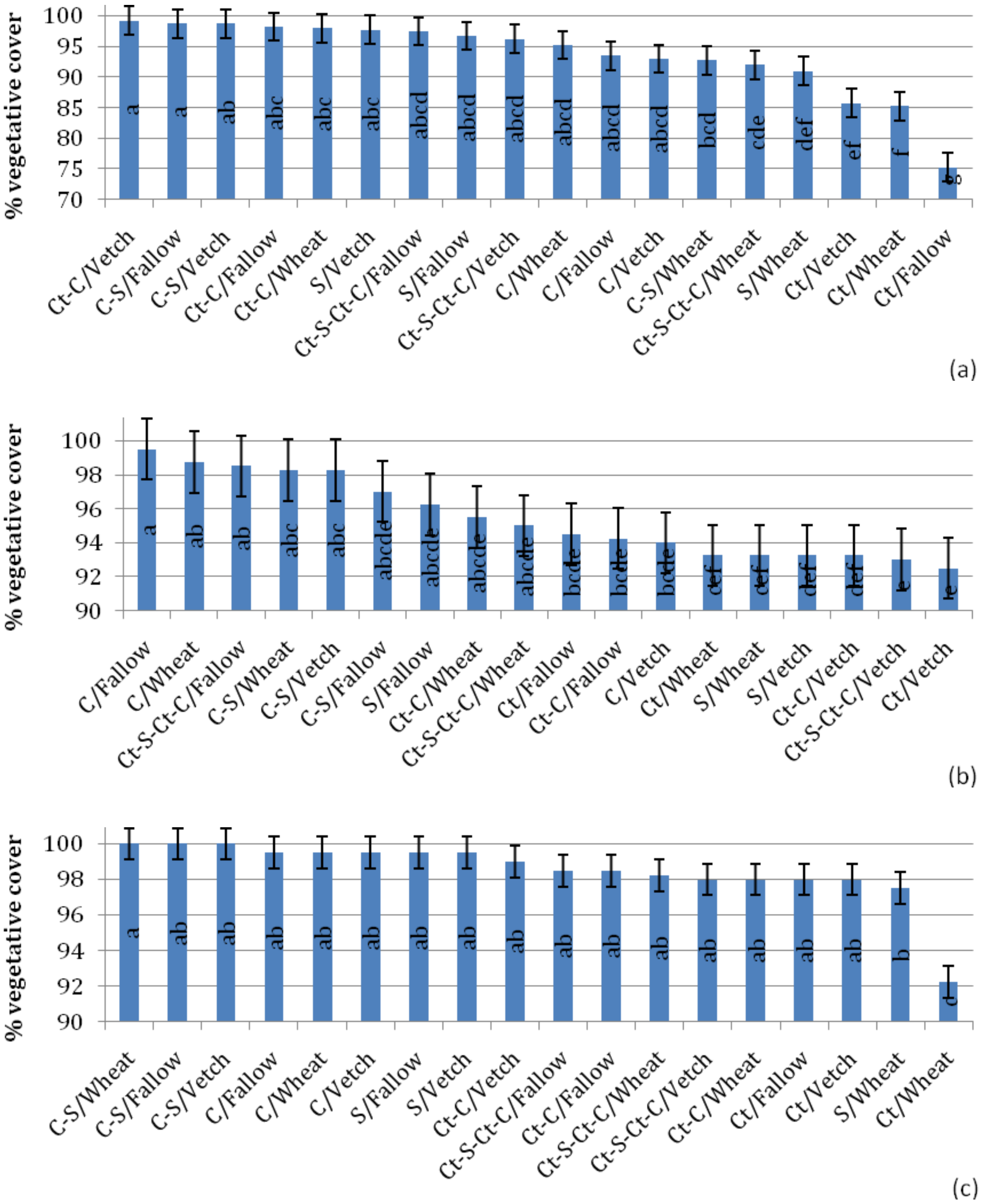

Figure 7. Differences in percent vegetative cover among cropping sequences in (a) spring 2006, (b) winter 2006-07, and (c) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

humid regions like the southeastern United States and the accumulation of residue on the surface under long-term no-tillage.

Continuous Cotton versus Cotton Rotations

In comparison to continuous cotton, the inclusion of corn in rotation with cotton resulted in consistent significant increases in percent vegetative cover during the spring following the corn crop, and under winter wheat this effect persisted into the subsequent spring. In spring 2006, the mean measured percent vegetative cover was significantly higher under the cotton/soybeans/cotton/corn and cotton/corn rotations than under continuous cotton under all winter treatments: winter fallow, winter wheat, and hairy vetch (Table 4, Figure 7a). In winter 2006-07, there were no significant differences in the mean measured percent vegetative cover between continuous cotton and the cotton rotations (Table 4, Figure 7b). In spring 2007, the mean measured percent vegetative cover was significantly higher under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat and cotton-wheat/corn-wheat rotations than under continuous cotton-wheat (Table 4, Figure 7c). This shows that, under winter wheat, this rotation effect on vegetative cover even continued into a subsequent spring in 2007, following the low residue-producing continuous cotton crop. In the same way, Krupinsky et al. (2007), in researching no-till cropping systems in North Dakota, reported carry-over effects of crops that produce larger amounts of residue, including spring wheat, proso millet, and grain sorghum, on vegetative cover following the next year's low residue-producing crops including lentil, chickpea, and sunflower. Likewise, Merrill et al.

(2006) reported that under no-till, the high residue-producing crops wheat and flax were essential in annual rotations with the two low residue-producing crops sunflower and dry pea in order to increase vegetative cover for adequate water and wind erosion control.

Continuous Soybeans versus Soybean Rotations

Compared to continuous monoculture of soybeans, the inclusion of corn in rotation with soybeans did not significantly increase vegetative cover in the spring, though it resulted in an increase in percent vegetative cover in the winter following the corn crop. There were no significant differences in the mean measured percent vegetative cover between continuous soybeans and the soybean rotations in spring 2006 and 2007 (Table 4, Figure 7a and c). In winter 2006-07, the mean measured percent vegetative cover was significantly higher under the corn-wheat/soybeans-wheat rotation than under continuous soybeans-wheat (Table 4, Figure 7b).

Winter Fallow versus Winter Cover Crops

With the exception of continuous cotton in spring 2006, the use of WCCs, compared to winter fallow, did not significantly increase percent vegetative cover and even had the opposite effect. In spring 2006, the mean measured percent vegetative cover was significantly higher under the corn-fallow/soybeans-fallow rotation than under the corn-wheat/soybeans-wheat rotation (Table 4, Figure 7a). Also in spring 2006, the mean measured percent vegetative cover was significantly higher under continuous cotton-wheat and continuous cotton-vetch than under continuous cotton-fallow (Table 4, Figure 7a). In winter 2006-07, the mean measured percent vegetative cover was significantly higher under winter fallow than under hairy vetch in the cotton/soybeans/cotton/corn rotation and continuous corn (Table 4, Figure 7b). In spring 2007, the mean measured percent vegetative cover was significantly higher under continuous cotton-fallow than under continuous cotton-wheat (Table 4, Figure 7c). Winter cover crops could have reduced vegetative cover relative to winter fallow by reducing winter weed growth, through competition, and hence limiting the ability of winter weeds to cover bare soil. The findings of the present study do not support previous research that show significant increases in percent vegetative cover because of using WCCs (Creamer et al., 1997; Kaspar et al., 2001; Reinbott et al., 2004; Ruffo et al., 2004). Our results suggest that WCCs do not significantly increase soil protection by vegetative cover in some no-till systems. Generally, close to 100 percent vegetative cover was provided by crop residue and annual winter weeds. Similarly, Havlin et al. (2005) suggested that the use of rye as a WCC following corn may contribute little to erosion protection given the dense surface layer of residue already provided by corn residue retention.

While the results of this study showed that all the no-till cropping systems, even without WCCs, maintained near complete vegetative cover, this has no bearing on the importance of WCCs on sloping erodible land. Plant growth is typically lower at convex landscape positions where soil is more erodible (Cox et al., 2003; Kravchenko and Bullock, 2002; Papiernik et al., 2005). Because erosion is more severe and annual winter weed biomass is less abundant on land with steeper slope gradients, planting WCCs are more effective for reducing erosion in these settings than they otherwise are on nearly level land (Personal communication, Donald Tyler, 2007). The use of WCCs as an erosion control practice on fields with low slope gradients, especially in no-till systems that maintain a full and thick layer of crop residue as protective mulch, can be inefficient and unprofitable (Schumacher et al., 2005). Precision conservation technology can improve the targeting of erosion control practices on zones across fields and watersheds that are particularly susceptible to degradation (Delgado et al., 2005).

Winter Wheat versus Hairy Vetch

Under most cropping sequences, winter wheat and hairy vetch plots had similar percent vegetative cover, though hairy vetch provided significantly greater vegetative cover in the spring than winter wheat under continuous monocropping of the relatively low residue-producing crops cotton and soybeans. In spring 2006, the mean measured percent vegetative cover was significantly higher under continuous soybeans-vetch than under continuous soybeans-wheat (Table 4, Figure 7a). In winter 2006-7, there were no significant differences in the mean measured percent vegetative cover between winter wheat and hairy vetch under all cropping sequences (Table 4, Figure 7b). In spring 2007, the mean measured percent vegetative cover was significantly higher under continuous cotton-vetch than under continuous cotton-wheat (Table 4, Figure 7c). Even though WCCs did not provide greater vegetative cover in this study, these results suggest that hairy vetch can be more effective for keeping the soil surface covered than winter wheat in certain cropping systems.

Particulate Organic Matter Carbon

Continuous Cotton versus Cotton Rotations

Compared to continuous monoculture of cotton, the inclusion of corn in a 2-year rotation with cotton can significantly increase POM-C at 0 to 5 cm. In spring 2006 and 2007, the mean measured POM-C content at 0 to 5 cm was significantly higher under the cotton-wheat/corn-wheat rotation than under continuous cotton-wheat (Table 5, Figure 8). Also in spring 2007, the mean measured POM-C content at 0 to 5 cm was significantly higher under the cotton-vetch/corn-vetch rotation than under continuous cotton-vetch. This is due to a higher amount of crop residues returned to the soil surface by the inclusion of corn in the cotton/corn rotation compared to residue inputs from continuous cotton. The increase in POM-C due to the addition of corn residue from the cotton-corn rotation not only occurred in spring 2006, following the 2005 corn crop, but even persisted into the subsequent spring of 2007. The results were consistent with those of Reddy et al. (2001), whose research reported that SOC at 0 to 5 cm in a no-till system in Mississippi increased significantly under a cotton/corn rotation relative to continuous monoculture of cotton, and attributed this effect to an increase in residue inputs by corn as compared to cotton. Several other studies have also reported greater SOC accumulation because of diversifying no-till cotton systems with rotations including crops such as corn or small grains that produce

Table 5. Effects of cropping sequences on particulate organic matter carbon at 0 to 5 and 5 to 15 cm

Treatments[#^]		Percent vegetative cover	
	Spring 2006	Winter 2006-07	Spring 2007
	97.5 (1.73) abcd	98.5 (1.73) ab	98.5 (1.91) ab
Ct-S-Ct-C/Fallow	92.0 (8.87) cde	95.0 (3.56) abcde	98.3 (3.50) ab
Ct-S-Ct-C/Wheat	96.3 (2.87) abcd	93.0 (4.32) e	98.0 (1.63) ab
Ct-S-Ct-C/Vetch	98.3 (0.957) abc	94.3 (4.99) bcde	98.5 (1.91) ab
Ct-C/Fallow	98.0 (1.41) abc	95.5 (1.91) abcde	98.0 (1.63) ab
Ct-C/Wheat	99.3 (0.957) a	93.3 (2.50) cef	99.0 (2.00) ab
Ct-C/Vetch	98.8 (0.500) a	97.0 (3.46) abcde	100 (0.00) ab
C-S/Fallow	92.8 (5.25) bcd	98.3 (1.26) abc	100 (0.00) a
C-S/Wheat	98.8 (1.89) ab	98.3 (2.36) abc	100 (0.00) ab
C-S/Vetch	75.3 (7.04) g	94.5 (2.65) bcde	98.0 (1.63) ab
Ct/Fallow	85.3 (7.54) f	93.3 (6.24) def	92.3 (4.19) c
Ct/Wheat	85.8 (2.06) ef	92.5 (3.32) e	98.0 (1.63) ab
Ct/Vetch	93.5 (7.19) abcd	99.5 (1.00) a	99.5 (1.00) ab
C/Fallow	95.3 (7.19) abcd	98.8 (1.50) ab	99.5 (1.00) ab
C/Wheat	93.0 (6.48) abcd	94.0 (7.35) bcde	99.5 (1.00) ab
C/Vetch	96.8 (2.99) abcd	96.3 (2.87) abcde	99.5 (1.00) ab
S/Fallow	91.0 (3.16) def	93.3 (4.11) def	97.5 (1.00) ab
S/Wheat	97.8 (3.30) abc	93.3 (2.36) cef	99.5 (1.00) ab
S/Vetch		P value	
	< 0.0001	0.0100	< 0.0001
Rotation	0.1255	0.2097	0.0641
WCC	0.0141	0.5942	0.0279
Rotation × WCC		Standard error	
	2.31	1.80	0.896

[#] Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

[^] Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability; Standard deviation is in parentheses.

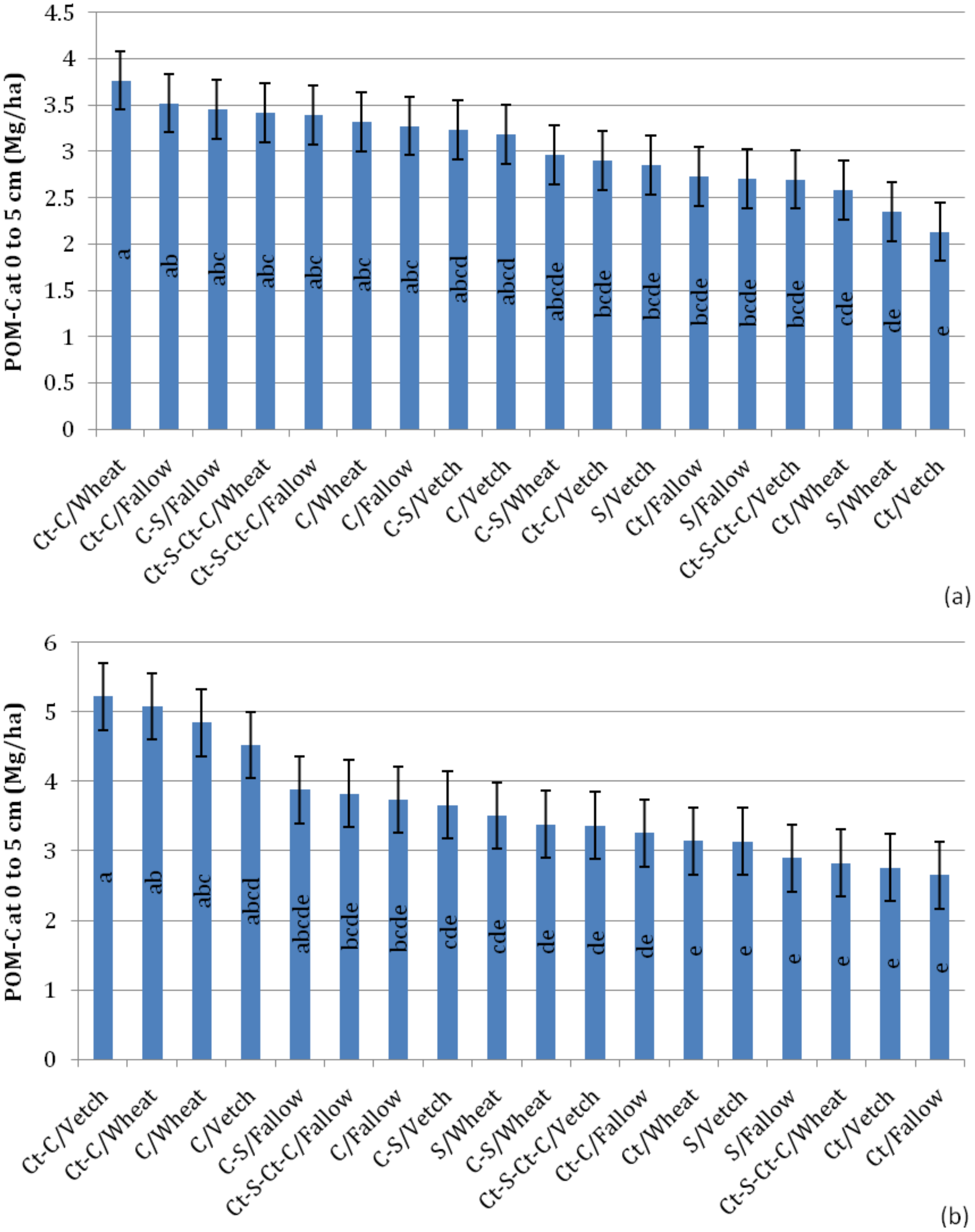

Figure 8. Differences in particulate organic matter carbon at 0-5 cm among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

greater amounts of residue, compared to cotton as a continuous monoculture (Acosta-Martinez et al., 2003; Causarano et al., 2006; Hulugalle et al., 2006; Abrahamson et al., 2007). In the springs of both 2006 and 2007, there were no significant differences in the mean measured POM-C content at 5 to 15 cm between continuous cotton and the cotton rotations (Table 5, Figure 9). The lack of differences is consistent with most previous studies, which have shown that changes in SOM in response to a change in cropping system do not occur below 5 or 7.5 cm (Bowman, 1999; McVay et al., 2006). Particulate organic matter is generally reported as more highly concentrated in the upper 5 cm of soil, and it decreases with depth, especially in no-till systems because of the retention of residue on the surface and microbial decomposition close to it (Janzen et al., 1992; Paustian et al., 1995; Franzluebbers and Arshad, 1996; Wander et al., 1998; Machado and Silva, 2001; Sa et al., 2001). For this reason, it is important that comparisons of SOM between tillage-based and no-till systems not be performed using sampling depths shallower than the plow layer (Reicosky et al., 1995; Bernoux et al., 2006). These results are also consistent with those presented in Ortega et al. (2002), who showed that after 8 years of no-till in Colorado, SOM was highly concentrated in the upper 5 cm. Longer than 4 or 5 years may be required for significantly increases in POM-C at 5 to 15 in response to the cotton rotations in the present study. Researchers have shown differences in labile SOM fractions due to crop rotations occurring between 9 and 58 years after the rotations were implemented (Franzluebbers et al., 1994, 1995; Doyle et al., 2004).

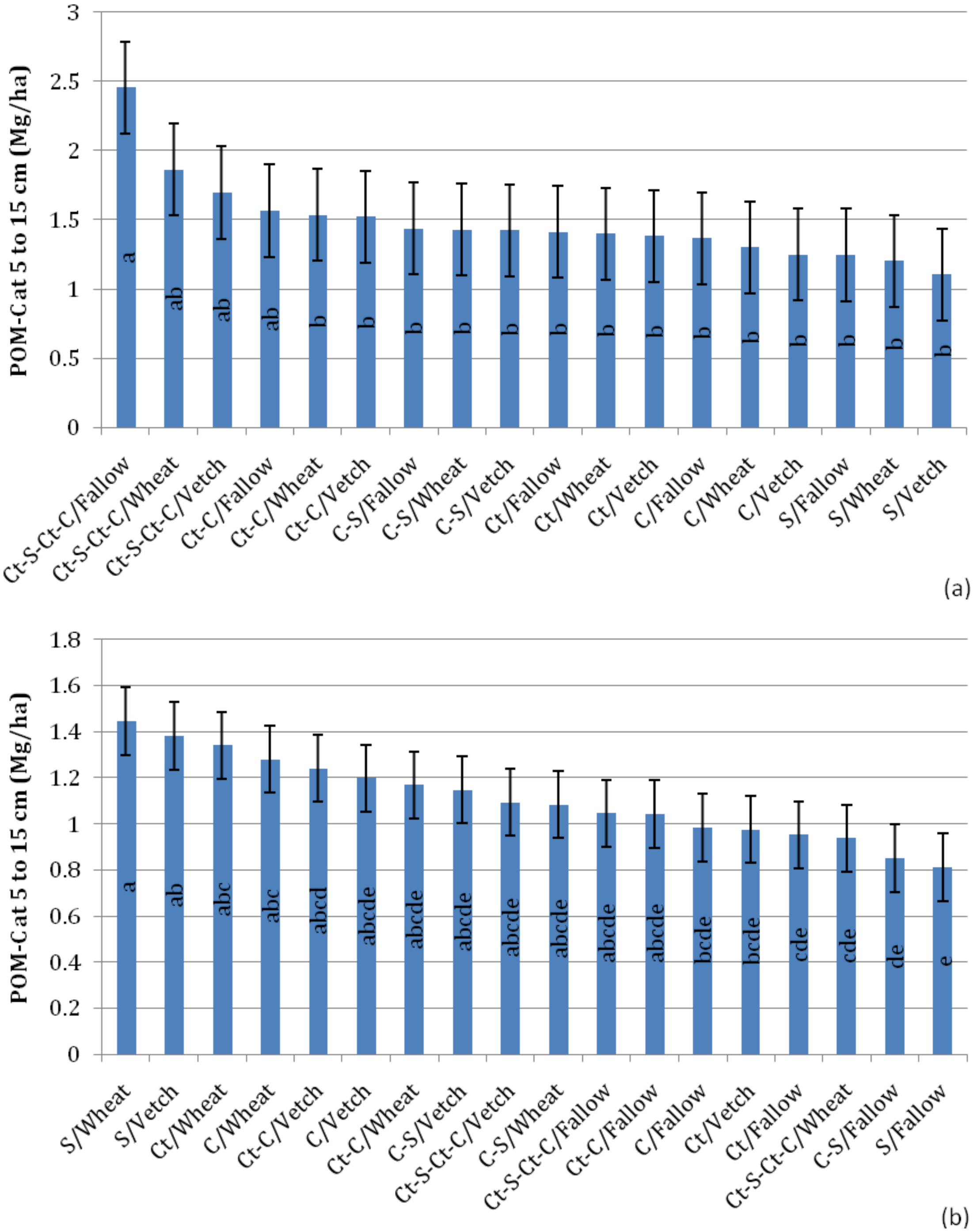

Figure 9. Differences in particulate organic matter carbon at 5 to 15 cm among cropping sequences in (a) spring 2006 and (b) spring 2007. Treatments with different letters at the center of each column are significantly different at the 5 percent level of probability. Error bars show standard error. Summer crop abbreviations: Ct, cotton; C, corn; S, soybeans; Last abbreviation in a rotation indicates the crop grown in 2005.

Continuous Soybeans versus Soybean Rotations

Compared to continuous monocropping of soybeans, the inclusion of corn in rotation with soybeans significantly increased POM-C at 0 to 5 cm, though this effect did not occur in spring 2007. In the spring of 2006, the mean measured POM-C content at 0 to 5 cm was significantly higher under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat and cotton-wheat/corn-wheat rotations than under continuous soybeans-wheat (Table 5, Figure 8). The higher residue production and slower residue decomposition of the previous corn crop of the soybean rotation compared to that of soybean residue returned to the soil under continuous soybeans could have caused these differences. These results are consistent with those of Wright and Hons (2004), who reported that, compared to continuous soybeans, a grain sorghum/wheat/soybean rotation, and a wheat/soybean rotation increased SOC in the surface soil under no-till management in south-central Texas. Similarly, many studies have reported a decline in SOM with the inclusion of soybeans in rotations; these studies attribute this effect to the relatively low amount and rapid decomposition of soybean residue (Havlin et al., 1990; Varvel, 1994a; Studdert and Echeverria, 2000). In spring 2007, there were no significant differences in the mean measured POM-C content at 0 to 5 cm between continuous soybeans and the soybean rotations (Table 5, Figure 8b). The potential increase in POM-C from corn residue inputs, like that observed in spring 2006, could have been offset by inhibitory effects of thick corn residue accumulated on the surface on plant productivity. Some of these negative effects shown in other studies include slowed spring soil warming (Kumar and Goh, 2000), excessively wet conditions (Blanco-Canqui et al., 2006), the promotion of plant diseases (Krupinsky et al., 2002), increased weeds or pests (Mann et al., 2002) or physical obstruction of WCC growth (Dormaar and Carefoot, 1996; Wolf and Eckert, 1999).

In contrast to POM-C at 0 to 5 cm, the inclusion of corn in rotation with soybeans significantly reduced POM-C at 5 to 15 cm. In spring 2006, the mean measured POM-C content at 5 to 15 cm was significantly higher under continuous soybeans-vetch than under the cotton-vetch/soybeans-vetch/cotton-vetch/corn-vetch and corn-vetch/soybeans-vetch rotations (Table 5, Figure 9a). In spring 2007, the mean measured POM-C content at 5 to 15 cm was significantly higher under continuous soybeans-wheat than under the cotton-wheat/soybeans-wheat/cotton-wheat/corn-wheat rotation (Table 5, Figure 9b). Inputs of soybean root residue may contribute significantly to POM-C at this depth, relative to cotton and corn root residue inputs, because of their lower C/N ratio.

Winter Fallow versus Winter Cover Crops

The WCCs generally did not increase POM-C at 0 to 5 cm, with the exception of greater POM-C under the cotton/corn rotation with the WCCs in spring 2007. In spring 2006, there were no significant differences in the mean measured POM-C content at 0 to 5 cm between winter fallow and the WCCs under all cropping sequences (Table 5, Figure 8a). The lack of a significant WCC effect on POM-C could due to the short period since the beginning of the experiment in 2002. Moreover, the sampling of soil nearly a year after the previous WCC termination, along with the relatively small amount of WCC residue produced, compared to high background levels of summer crop residue inputs, likely contributed to the absence of a WCC effect. Additionally, inputs of WCC residue through root turnover and rhizodeposition during WCC growth could have resulted in a priming of native SOM, increasing SOM decomposition (Bell et al., 2003). This priming effect could have somewhat counterbalanced the contributions of WCC residue following their termination in the spring of the previous year. Our results disagree with the conclusions of some studies that report an increase in SOM under WCCs compared to winter fallow in no-till systems (Entry et al., 1996; Sisti et al., 2004; Amado et al., 2006; Causarano et al., 2006; Katsvairo et al., 2006; Sainju et al., 2006). For example, Entry et al. (1996) showed that WCCs in Alabama's "Old Rotation" experiment significantly increased total SOM-C and N, microbial biomass-C and N, and crop yields over the long term. Then again, other studies have reported that, the use of WCCs, as compared to winter fallow, did not increase SOM (Eckert, 1991; Mendes et al., 1999; Shrestha et al., 2002; Kaspar et al., 2006). For example, Kaspar et al. (2006) showed that the cereal WCCs oat, rye, and an oat-rye mixture did not significantly increase SOC at 0 to 5 and 5 to 10 cm in a no-till corn-soybean rotation in Iowa. On the other hand, in spring 2007 in the current study, the mean measured POM-C contents at 0 to 5 cm were significantly higher under the cotton-wheat/corn-wheat and cotton-vetch/corn-vetch rotations than under the cotton-fallow/corn-fallow rotation (Table 5, Figure 8b). These results are consistent with Causarano et al. (2006), who reviewed 20 studies of cotton systems in the southeastern United

States and showed that in no-till systems, the inclusion of a WCC resulted in significantly higher SOC sequestration rates than without a WCC. The greater POM-C content under hairy vetch could be due to a greater amount of vetch biomass C relative to winter weed biomass C returned to the soil, which is consistent with studies that have demonstrated that SOM increases as the total input of crop residue increases (Rasmussen et al., 1980; Kuo et al., 1997; Kuo and Jellum, 2002). The current results support those of Sainju et al. (2006), who reported that a greater portion of SOC at 0 to 10 cm was derived from WCC residue than from winter weed residue under no-till management. Similar to the observation in this study of an increase in labile SOM with increasing cropping intensity with WCCs, many studies in no-till dryland farming systems have shown that reducing the summer fallow period, and thus increasing crop residue production, significantly increases SOM (Halvorson et al., 2002; Ortega et al., 2002; Sherrod et al., 2005; Sainju et al., 2007b).

Under most cropping sequences in the current study, the WCCs had no significant effect on POM-C at 5 to 15, though hairy vetch significantly impacted POM-C at this depth under continuous soybeans. The results of the current study also support Smith et al. (1987), who suggested that WCCs under no-till do not significantly contribute to SOM, and with the previously mentioned studies that report no significant impacts of WCCs on SOM (Eckert, 1991; Mendes et al., 1999; Shrestha et al., 2002; Kaspar et al., 2006). In spring 2006, the mean measured POM-C content at 5 to 15 cm was significantly higher under continuous soybeans-vetch than under continuous soybeans-fallow (Table 5, Figure 9a). In spring 2007, the mean measured POM-C content at 5 to 15 cm was significantly higher under continuous soybeans-wheat and continuous soybeans-vetch than under continuous soybeans-fallow (Table 5, Figure 9b). The greater POM-C content observed under WCCs than under winter fallow is due to a greater amount of WCC biomass C, particularly belowground WCC residue C inputs, relative to winter weed biomass C returned to the soil. These differences agree with the findings of Sainju et al. (2006), who reported that in a no-till cotton-sorghum rotation in Georgia, rye and a hairy vetch-rye mixture significantly increased SOC at 10 to 30 cm compared to winter fallow. The greater POM-C with WCCs is also consistent with Villamil et al. (2006), whose research showed that, in a no-till system in Illinois, the corn-cereal rye/soybeans-hairy vetch and corn-cereal rye/soybeans-cereal rye-hairy vetch mixture rotations, as compared to a corn/soybean rotation without WCCs, increased SOM within the 5 to 15 cm layer, as well as down to 30 cm. Though WCCs did not consistently increase POM in the no-till cropping systems of the present study, they may be more effective in this function at more highly erodible landscape positions (Terra et al., 2005).

Winter Wheat versus Hairy Vetch

Particulate organic matter C at 0 to 15 cm was generally insensitive to differences between winter wheat and hairy vetch, with the exception of a significant difference under the cotton/corn rotation in spring 2006. In spring 2006, the mean measured POM-C content at 0 to 5 cm was significantly higher under the cotton-wheat/corn-wheat rotation than under the cotton-vetch/corn-vetch rotation (Table 5, Figure 8a). The increase in POM-C under winter wheat relative to hairy vetch reflects the potential differences in plant biomass quantity and quality between the two cover crops. The narrow C/N ratio of the hairy vetch biomass relative to winter wheat biomass can stimulate greater microbial decomposition of labile SOM, resulting in less POM-C. In spring 2007, there were no significant differences in the mean measured POM-C content at 0 to 5 cm between winter wheat and hairy vetch under all cropping sequences (Table 5, Figure 8b).

Particulate organic matter C at 5 to 15 cm did not vary under the WCC species winter wheat and hairy vetch, excluding a significant difference in POM-C between these WCCs under continuous soybeans in spring 2006. In spring 2006, the mean measured POM-C content at 5 to 15 cm was significantly higher under continuous soybeans-vetch than under continuous soybeans-wheat (Table 5, Figure 9a). Similar this result showing that a leguminous WCC, hairy vetch, increased SOM relative to a cereal WCC, winter wheat, Villamil et al. (2006) reported that the inclusion of hairy vetch in corn/soybean rotations, as the cropping sequences corn-cereal rye/soybeans-hairy vetch and corn-cereal rye/soybeans-hairy vetch-cereal rye mixture, increased SOM in comparison to corn-cereal rye/soybeans-cereal rye. Due to its low C/N ratio, hairy vetch residue can contribute more N than winter wheat, particularly through root residue inputs, for soil microorganisms and fauna, increasing their capacity to attack and transform residue into SOM (Villamil et al., 2006). External inputs of N, such as that from hairy vetch in our study, are important to SOM accumulation because they increase biomass production

(Drinkwater, 1998; De Maria et al., 1999) and interact with inorganic N inputs to enhance each of their individual effects on SOM (Moran et al., 2005). In addition to residue quality, differences in rooting characteristics and rooting depths between winter wheat and hairy vetch may also play significant roles in differing contents of POM-C at 5 to 15 cm (Benjamin et al., 2007). In spring 2007, there were no significant differences in the mean measured POM-C content at 5 to 15 cm between winter wheat and hairy vetch under all cropping sequences (Table 5, Figure 9b). This lack of a significant difference in POM-C between WCCs could be due to the factors mentioned previously regarding the lack of a significant effect of WCCs on POM-C compared to winter fallow for this depth. In light of the general lack of differences in subsurface POM between hairy vetch and winter wheat, this study does not support the findings of Sainju et al. (2002), who showed that compared to other WCC species, hairy vetch was particularly well-adapted to the southeastern United States for maintaining and contributing to SOM, especially under no-till.

IV. CONCLUSIONS

There were significant positive effects in western Tennessee on key soil quality indicators from including a high residue-producing crop such as corn in cotton no-till systems in western Tennessee. Compared to continuous cotton, the inclusion of corn in rotation with cotton significantly increased aboveground crop residue quantity, aboveground winter weed biomass quantity, total aboveground biomass, percent vegetative cover, and POM-C at 0 to 5 cm, though it decreased aboveground winter weed biomass C/N ratio. Compared to continuous monocropping of soybeans, the inclusion of corn in rotation with soybeans significantly increased POM-C at 0 to 5 cm and aboveground crop residue quantity, though it significantly decreased aboveground winter wheat biomass quantity, total aboveground biomass quantity under winter wheat, aboveground winter weed biomass C/N ratio, and POM-C at 5 to 15 cm. In addition, the soybean rotations did not significantly increase percent vegetative cover relative to continuous soybeans. Clearly, the inclusion of corn in cotton rotations was highly effective in improving most of the soil health indicators. In contrast, the inclusion of corn in the soybean rotations overall was ineffective at improving the soil health indicators.

Generally, there were no significant positive effects of the WCCs in place of winter fallow on key soil quality indicators relating to vegetative cover and labile SOM. Compared to winter fallow, the use of WCCs did not significantly increase the dry weight quantity of total aboveground biomass under most cropping sequences and significantly reduced aboveground crop residue quantity, aboveground winter weed biomass quantity, and percent vegetative cover. Furthermore, the WCCs did not significantly increase POM-C at 0 to 5 and 5 to 15 cm, with the exception of the significantly greater POM-C at 5 to 15 under winter wheat and hairy vetch than under winter fallow in continuous soybeans. Taken as a whole, the measured soil health indicators did not improve with WCCs. Our results indicate that the use of WCCs has limited value for increasing vegetative cover or increasing the labile pool of SOM under no-till management in western Tennessee. Although vegetative cover was virtually complete even without WCCs in our study on flat land, at landscape positions with higher slope gradients the use of WCCs may contribute significantly to soil protection by vegetative cover. Relative to winter wheat, hairy vetch had significantly lower aboveground WCC biomass C/N ratios, significantly decreased aboveground winter weed biomass C/N ratio, significantly increased aboveground winter weed biomass, and under continuous monocropping, significantly increased percent vegetative cover. Greater winter weed growth and vegetative cover under hairy vetch may improve soil quality over the long term relative to winter wheat.

While the results from a one-year study such as this may reflect climatic or environmental variation, short-term studies can collectively provide reliable data indicating management effects on soil quality (Rasmussen, 2002; Personal communication, Daniel Yoder, 2007). Future research could investigate potential adverse effects of a thick layer of residue on the surface associated with no-till cropping systems, including changes in soil temperature and moisture (Lal, 2004), SOC distribution throughout the profile (Puget et al., 2005), and N cycling rates

(Martens, 2001). Monitoring spatial and temporal changes of a multiplicity of soil health indicators as affected by crop rotations and WCCs under no-till in western Tennessee and other representative sites in the southeastern United States could provide a regional assessment of the effectiveness of these promising conservation-oriented management practices. Government incentive programs such as the Conservation Security Program should encourage the beneficial services provided by crop rotations and WCCs that consistently and markedly improve soil quality indicators under no-till management (Robertson and Swinton, 2005). The conclusions of this present study may also apply to comparable agroclimatic regions, possibly where institutional, resource, and environmental constraints threaten food security and the transition to agricultural sustainability (Ruttan, 1999).

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