Carbon and Nitrogen Cycling under Conservation and Conventional Tillage in Peanut and Collard Agroecosystems

by

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Abstract

Although there has been considerable adoption of conservation tillage by agronomic and vegetable producers in the US, information on nutrient release from organic residues is lacking. Information on release of nutrients from organic residues will help producers make informed decisions regarding residue management, including adoption of conservation or conventional tillage. The objectives of this study were: 1. to assess mass loss rates and carbon (C) and nitrogen (N) release rates from organic residues (organic mulches, peanut (*Arachis hypogaea*), and summer cover crops) under conventional and conservation tillage, and 2. to determine changes in soil C and N, aggregate stability, and yield during no-till herbicide-free collard (*Brassica oleracea* L. var. Champion) production using high biomass cover crops and organic mulches over a three year period.

The collard study was conducted during 2005-2008 in eastern central Alabama, USA. A summer cover crop of forage soybean (*Glycine max* (L.) Merr. cv. Derry) or no summer cover crop control were established into killed winter rye (*Secale cereale* L. cv. Elbon) residue. Collards were transplanted into killed summer residue in the fall, followed by mulching with *in situ* organic residues three weeks later and fertilized with 202 kg N ha^{-1}. Mulches applied at 6.7 Mg ha^{-1} yr^{-1} did not mineralize nutrients in sufficient quantities to meet collard demands after three years, although the crop appeared healthy. All treatments, including controls, improved soil organic C in the 0-5

cm soil depth over three years. At the end of three years, treatments did not affect collard yield or aggregate stability compared to the control.

Mulch decomposition studies of mimosa (*Albizia julibrissin* Durazz.), lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don), oat (*Avena sativa*) straw, and soybean (*Glycine max* var. Stonewall) residues were conducted using litterbag methodology and applied at a rate equivalent to 6.7 Mg ha^{-1} during 2007-2008 in eastern central Alabama, USA. Buried residues decomposed faster than surface residues, particularly in the labile portion. More N was potentially available to spring crops from surface residues, which may act as a slow release fertilizer, compared to incorporated residues. At spring planting, mimosa residue contained 78 kg N ha^{-1} when buried the previous fall, compared to 123 kg N ha^{-1} when left on the soil surface. Surface placed mimosa mineralized 33% of initial N content after one year, compared to 71% when buried. Similarly, C was sequestered for longer periods when residue was placed on the surface compared to incorporation. Aboveground soybean residue decomposed too quickly to warrant a N credit to subsequent crops. However, organic residues with an intermediate C:N ratio may be utilized under conservation tillage for the enhancement of soil organic matter (SOM), C sequestration, and soil N status.

Peanut residue decomposition studies were conducted at Rocky Mount, NC and Headland, AL, USA using litterbag methodology at a rate equivalent to 3.5 Mg ha^{-1} during 2004-2005. Residues of three peanut varieties were buried and surface-placed at both locations. In NC, buried residues mineralized N at higher rates than surface residues during the initial 50 days of decomposition. After the initial rapid phase of decomposition, there was no difference in rates of N release at either location. No

treatment differences were found at the Wiregrass Experiment Station. These data suggest that N is released too quickly from peanut residue to warrant N credits to subsequent crops. This conclusion was supported by a laboratory microlysimeter incubation study conducted on the same three peanut varieties on a Dothan soil.

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List of Abbreviations

ADF	Acid detergent fiber
ADL	Acid detergent lignin
AFDW	Ash free dry weight
AIA	Acid insoluble ash
AL	Alabama
ANOVA	Analysis of variance
C	Carbon
CC	Cover crop
cm	Centimeter
CSA	Community Supported Agriculture
cv	Cultivar
d	Days
DAM	Days after mulching
g	Gram
ha	Hectare
HC	Hemicellulose
ICAP	Inductively coupled argon plasma spectrophotometry
kg	Kilogram
m	Meter
Mg	Megagram

mg	Milligram
N	Nitrogen
NC	North Carolina
NDF	Neutral detergent fiber
n/s	Not significant
P	Phosphorus
SARE	Sustainable Agriculture Research and Education
SOC	Soil organic carbon
SOM	Soil organic matter
t	Tons
TSN	Total soil nitrogen
USDA	United States Department of Agriculture
WGS	Wiregrass
yr	Year

I. Introduction

Conservation Tillage

Conservation tillage is defined as agricultural production that leaves at least 30% residue on the soil surface after planting, and may include no-till, ridge till, mulch-till, and strip-till (Uri, 1999). Conservation tillage is known to reduce soil erosion, increase soil organic matter (SOM) content, limit phosphorus (P) runoff and improve soil infiltration (Uri, 1999), soil structure and aggregate stability (Riley et al., 2008), thereby benefiting producers and the environment alike. Other advantages of conservation tillage include reduced energy and labor costs (Siemans and Doster, 1992) and increased soil moisture retention (Li et al., 2008). Disadvantages of conservation tillage may include reduced weed control, delayed planting dates due to lower soil temperatures in spring, and equipment costs (Gupta et al., 1988; Rutledge, 1999). However, conventional tillage has been shown to destroy organic matter, increase erosion, damage soil structure, reduce aggregate stability, promote crusting and decrease soil moisture compared to no-till (Bessam and Mrabet, 2003; Raczkowski et al., 2002).

Agricultural production in the US has seen a marked increase in adoption of conservation tillage in recent decades. Between 1998 and 2005, no-till corn (*Zea mays*) acreage in the US increased from 9.2 million to 18.6 million acres, while conventionally tilled corn acreage decreased from 24.5 million to 20.6 million acres over the same period

(USDA, 2008b). The two systems can be expected to release nutrients from organic residues at different rates, and thereby affect the soil nutrient status for succeeding crops. Nutrient release rates from organic mulches and cover crops need to be determined in order to optimize synchronicity with nutrient uptake by succeeding crops.

In 2008, 1.31 million acres of peanut (*Arachis hypogaea*) were planted with an average of 13.6% soil coverage after planting (USDA, 2008b). This compares with 1.24 million acres in 1999 averaging 3.9% residue remaining on the surface after planting. Cultivation for weed control decreased from 65% of all planted peanut acreage in the US in 1999 to 34% in 2008 (USDA, 2008b). The trend toward reduced tillage is due to the adoption of conservation tillage among peanut producers. Conservation tillage peanut production usually utilizes strip tillage (Wright et al., 2006).

Residue Composition and Decomposition

The decomposition of C rich organic residues such as straw may result in reduced N availability as the soil microbial community temporarily immobilizes ammonium and nitrate in competition with plants. The use of N fertilizer may circumvent this problem by lowering the C:N ratio. It is desirable to strike a balance between mulch N content and mulch persistence. On the other hand, C rich mulches can reduce nitrate leaching after harvest via immobilization (Doring et al., 2005).

Attempts to model decomposition rates of organic residues to elemental and fiber analyses are of limited predictive value because they often do not consider environmental variables (Stroo et al., 1989) such as temperature (Rao and Dao, 1994), rainfall (Rao, 1989; Rao and Dao, 1994), cultural practices (Chalau et al., 1995; Collins et al., 1990),

and location (Chalau et al., 1995; Rao, 1989). Furthermore, fiber content of individuals within a species often vary. For example, the fiber content of straw has been shown to vary with crop species (Berg and Tamm, 1991; Berg and Tamm, 1994; Goh and Tutua, 2004; Hadas et al., 2004), cultivar (Sheaffer et al., 1994; Stubbs et al., 2009), and year (Stubbs et al., 2009). Carbon:N ratios are commonly used to determine if residues will mineralize or immobilize inorganic N (Hadas et al., 2004), but often the inclusion of lignin, polyphenol, lignocellulose, and acid detergent fiber (ADF) are used to describe decay patterns (Giller and Cadisch, 1997).

Acid detergent fiber represents cellulose, lignin, silica, insoluble crude protein, and ash, and represents the least soluble components of residue cell walls. Acid detergent lignin (ADL) is an estimate of the total lignin content. Lignin is a high molecular weight polyphenolic compound whose precise structure defies elucidation, but is one of the most recalcitrant fractions of organic residue. Neutral detergent fiber (NDF) represents the insoluble components of cell walls (cellulose, hemicellulose and lignin). Acid detergent fiber is a measure of cellulose and lignin (Stubbs et al., 2009). Acid detergent fiber – ADL = cellulose content. Cellulose is a structural polysaccharide in primary cell walls. Neutral detergent fiber – ADF = hemicellulose content, which is also a structural component of cell walls but is a shorter chain polysaccharide and is therefore more labile than cellulose. Acid insoluble ash (AIA) represents the amount of ash that is insoluble in dilute hydrochloric acid. Polyphenols are an estimate of tannin content in residue. Rapid decomposition is usually directly related to a low C:N ratio and high hemicellulose content (Goh and Tutua, 2004). As residue decomposition proceeds the composition of the residue changes. As time proceeds, correlations between initial fiber quality and the

later stages of residue decomposition become less significant (Heal et al., 1997) because proteins, nucleic acids, cellulose and hemicellulose decompose relatively quickly, and the later stages of decomposition are governed more by lignified carbohydrates, large polyphenols, and lignin (Berg and Staaf, 1980). Therefore, correlations between fiber quality and decomposition are more evident during the initial stages of decomposition.

Studies conducted in Georgia (Wilson and Hargrove, 1986) found that the decomposition of leguminous winter cover crop residue and release of N for subsequent crops. The authors reported that green manures decompose rapidly in warm southern soils and that they could be a significant source of N to following crops. A study conducted in Kentucky concluded that a winter cover crop of vetch did not reduce the need for N fertilization in subsequent corn (Utomo et al., 1990). However, a previous study, also conducted in Kentucky, came to the opposite conclusion (Ebelhar et al., 1984). The practicality of N synchronicity from decaying residue to subsequent crops remains in question and warrants further investigation.

Cover Crops

A crucial factor to the success of conservation tillage is the production of high biomass cover crops. High biomass cover crops are desirable because they contribute substantial amounts soil organic matter (SOM), cover a large percentage of the soil surface, and enhance weed suppression. Winter rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) are common winter cover crops used in the southeastern US (Ashford and Reeves, 2003). The residues from these cover crops have a high C:N ratio, as well as high cellulose and lignin contents, which slow their decomposition and persist

well into the growing season. However, high biomass summer cover crops with low C:N ratios such as sunn hemp (*Crotalaria juncea* L.) or forage soybean (*Glycine max*) require additional weed control later in the growing season because they have a low C:N ratio and low fiber content (Ron Morse, personal communication, May 17, 2005).

Residue Decay Models

Decomposition of organic residue occurs in two phases. Initially, a labile portion of the residue, such as sugars, starches and proteins, is readily consumed by soil microbes, leaving behind a recalcitrant portion of the residue, such as cellulose, fats, waxes, lignin and tannins (Wieder and Lang, 1982). This recalcitrant portion is slowly decomposed and contributes to the development of SOM. Such decomposition systems are best described by double exponential decay models, with one exponential term describing labile portion decay and the other exponential term describing the recalcitrant portion of the residue (Wieder and Lang, 1982). The double exponential decay model is represented by the equation:

$$Y = Ae^{-k_1 t} + Be^{-k_2 t} \quad \text{(Equation 1)},$$

where Y = the nutrient or mass remaining, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application. Such models have adequately described field litterbag decomposition studies in Haiti (Isaac et al., 2000). When litter decomposes quickly, resulting in a nearly linear response from the recalcitrant portion of the residue, k_2 becomes very small, and the double exponential decay model collapses into a single exponential decay model.

No-Till Vegetable Production

The perceived benefits of conservation tillage during agronomic crop production have spurred increased interest in no-till vegetable production in the US. Killed cover crop mulches have proven effective for no-till production of sweet potatoes (*Ipomoea batatas* (L.) Lam.) in South Carolina (Jackson and Harrison, 2008). The same study showed that soil insect pests were no greater in no-till than in conventionally tilled sweet potato production. No-till with winter cover crops has been successful in winter rye – sweet corn (*Zea mays* L.) – bell pepper (*Capsicuum annuum* Mill.) and winter rye – sweet corn – cucumber (*Cucumis sativus* L.) production, with yields surpassing those of winter bare soil rotations in Oklahoma (Russo and Kindiger, 2007).

Cool season vegetables have also been successfully produced under conservation tillage. Although yields of spring cabbage (*Brassica oleracea* L. Capitata group) have been shown to be lower under conservation tillage than bare soil, soil erosion was reduced under conservation tillage with killed rye residue (Roberts et al., 1999). Strip-till production of cabbage in South Carolina was found to have a lower incidence of *Alternaria* than a conventional chemical production system due to reduced leaf-soil contact in the reduced tillage system, and had the same amount of pressure from *Lepidoptera* pests (Hoyt and Walgenbach, 1995).

While mulching material is typically obtained *in situ* from killed winter cover crops, additional weed control during the growing season. Particularly in the case of fall crop production, such as *Brassicaceae* production, residue may not persist long enough to adequately suppress weeds. However, the inclusion of a summer cover crop may improve weed suppression while simultaneously increasing surface residue biomass. The

inclusion of both winter and summer cover crops may enhance SOM content. However, there is the possibility of increased N immobilization if both summer and winter cover crops are high C:N species, such as in a winter rye - millet - *Brassicaceae* rotation. Therefore, it may be more productive to include a high biomass legume cover crop, such as forage soybean (*Glycine max* (L.) Merr.), into the rotation. Derry forage soybean has the potential to produce 23% more biomass than a grain-type cultivar and is not intended for grain production (Devine et al., 1998). Nitrogen contributed from soybean residue has potential to reduce the C:N ratio of killed winter cover crops, reducing the potential for N immobilization during Fall crop production. Additionally, symbiotic N fixation by soybean has the potential to supply additional N to subsequent crops during root decay.

Due to the high fiber quality of soybean residue, it will likely not persist long enough to aid in weed suppression during the *Brassicaceae* growing season, and may therefore necessitate further weed control. Traditionally, additional weed control under conservation tillage systems is facilitated by the use of selective herbicides. Alternatives to herbicide application may be desired by various producers, such as transition organic producers, certified naturally grown producers, or those who seek to market herbicide-free vegetables to meet consumer demand. Traditional organic weed control, such as hoeing or cultivating, are off-limits to those who adopt conservation tillage because of the need to retain residue on the soil surface. Flame weeding under conservation tillage is dangerous if improperly managed due to possibility of igniting desiccated residue.

Mulching for improved weed control under herbicide-free conservation tillage can be expensive if the materials are purchased and transported to the production area (Runham and Town, 1995). However, mulches can be economically feasible if they are

obtained on-farm (Merwin et al., 1995). Producers who wish to produce *in situ* mulch may do well to consider the use of perennial leguminous species, such as *Lespedeza* (*Lespedeza cuneata* (Dum. Cours.) G. Don) and mimosa prunings. A plot of land devoted to these potentially invasive species, once established, can produce mulches that simultaneously persist throughout the growing season due to their woody stems, but also balance the high C content of stems with leaves that have high N contents. Since these species are potentially invasive (USDA, 2009b), it is possible that these species already exist on the farm. In such a case, utilization of perennial leguminous species as on-farm mulching material would help to keep invasiveness under control while simultaneously limiting production and/or transportation costs associated with mulch production. The perennial nature of such species also circumvents the need to establish new mulch material annually, as in the case of straw mulch production.

Objective

The objectives of this study were to: 1. assess mass loss rates and carbon (C) and nitrogen (N) mineralization rates from organic residues (organic mulches, peanut, and summer cover crops) under conventional and conservation tillage, and 2. determine changes in soil C and N, aggregate stability, and yield during no-till herbicide-free collard (*Brassica oleracea* L. var. Champion) production using high biomass cover crops and organic mulches over a three year period.

II. Carbon and Nitrogen Release and Persistance from Organic Residues

Abstract

Traditional organic vegetable production relies on tillage for weed control, but organic producers may adopt no-till if sufficient weed suppression can be achieved. A combination of high biomass cover crops with organic mulches may provide vegetable producers with multiple benefits, but information on nutrient release from these residues is lacking. The objective of this study was to assess nutrient release rates and mass loss from mimosa (*Albizia julibrissin* Durazz.), lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don), oat (*Avena sativa*) straw, and soybean (*Glycine max* (L.) Merr.) under conventional and conservation tillage. The experiment was conducted in S. Tallassee, AL on a Wickham fine sandy loam, 0 to 2 percent slopes (Fine-loamy, mixed, semiactive, thermic Typic Hapludults) using litterbag methodology and consisted of a split plot design (main plot - 2 tillage systems; subplots - 4 residue types) with four replicates. Nitrogen (N) and carbon (C) release and mass loss rates were determined. Buried residues decomposed faster than surface residues, particularly in the labile portion. More N was potentially available to spring crops from surface residues, which acted as a slow release fertilizer, compared to incorporated residues. At spring planting time, mimosa residue contained 78 kg N ha^{-1} when buried the previous fall, compared to 123 kg N ha^{-1} when left on the soil surface. Buried soybean residue contained 39 kg N ha^{-1} at spring

planting time, while surface placed soybean residue contained 72 kg N ha^{-1}. Results were similar for lespedeza (72 vs. 101 kg N ha^{-1}, respectively), but not for straw (24 vs. 26 kg N ha^{-1}, respectively). Surface placed mimosa residue mineralized 33% of initial N content after one year, compared to 71% when buried. Similarly, surface placed lespedeza mineralized 36% of initial N after one year, compared to 64% when buried. However, soybean residue mineralized N quickly regardless of placement (73% when surface placed vs. 87% when buried). Straw did not mineralize appreciable amounts of N regardless of placement because of its low initial N content. Similarly, C was sequestered for longer periods when any residue was placed on the surface compared to incorporation. This study demonstrates that *in situ* cover crops and mulches may be utilized under conservation tillage for the enhancement of soil organic matter (SOM), C sequestration, and soil N status.

Introduction

Traditionally, organic vegetable producers utilize cultivation or hand weeding for weed control, though feasible methods of weed control in organic conservation tillage systems include hand-weeding, brush weeding, mowing, cutting, flaming (Bond and Grundy, 2001; Peigne et al., 2007), and the use of plastic, fabric or organic mulches (Feldman et al., 2000). One alternative to tillage for weed control is the utilization of high biomass cover crops and organic mulches. Applied in sufficient quantities, high biomass residues, either grown as cover crops or applied as mulches, have been shown to suppress weeds, limit erosion and conserve soil moisture (Rathore et al., 1998).

Mulching may include living mulches, plastic, paper, or loose organic materials and are employed primarily for weed control. Living mulches are mainly used for perennial crop production (Ingels et al., 1994), and require careful selection and management in order to limit competition with the main crop (Costello and Altieri, 1994). Woven polypropylene mulches are also usually used for persistent weed control in perennial crops (Bond and Grundy, 2001). Polyethylene plastic mulches are widely used for both conventional and organic vegetable production, but cleanup and disposal are problematic. Paper mulches have been shown to suppress weeds in transplanted vegetable production, with control similar to that of black plastic (Runham and Town, 1995). Most annual and some perennial weeds were suppressed using 0.8-1.4 t ha^{-1} of shredded newspaper during sweet corn (*Zea mays* L., var. Saccharata (Surt.)), field corn (*Z. mays* L.), soybean, and tomato (*Lycopersicon esculentum* Mill.) production (Munn, 1992). Paper mulches are biodegradable, thereby eliminating the labor and cost associated with plastic mulch removal while improving environmental sustainability.

Loose organic mulches are also biodegradable, but have the advantage of releasing nutrients as they decompose. The quantity needed to suppress weeds may make them cost prohibitive if they are purchased and transported to the production area, but may be economically feasible if they are produced *in situ* (Merwin et al., 1995). It was found that using cut ryegrass (*Lolium* spp.) as mulch was more economical than cultivation for weed control during tomato and pepper (*Capsicum annuum*) production (Edwards et al., 1995). It is important to ensure that straw does not contain seeds in order to circumvent volunteer infestation (Yordanova and Shaban, 2007).

Decomposition of the organic mulch residue may have allelopathic effects on weeds as well as on the cash crop by releasing natural phytotoxins (Wallace and Bellinder, 1992). Russo *et al.* (1997) found that mulching with fresh kenaf (*Hibiscus cannabinus* L.) chips reduced cabbage (*Brassica oleracea* L.) yields but did not affect onion (*Allium cepa* L.) yields, a phenomenon attributed to allelopathy of the fresh mulch. The same study showed similar weed control between black plastic mulch and kenaf chips.

Additionally, the decomposition of C rich mulches such as straw may result in reduced N availability as the soil microbial community temporarily immobilizes ammonium and nitrate in competition with plants. The use of N rich mulches may circumvent this problem by lowering the C:N ratio, though residue with higher N contents tend to decompose faster. Therefore, it is desirable to strike a balance between mulch N content and mulch persistence. On the other hand, C rich mulches can reduce nitrate leaching after harvest via immobilization (Doring et al., 2005).

There is evidence that mulching several weeks after transplanting can improve weed suppression mainly by improving mulch persistence later into the growing season (Law et al., 2006), but mulch application should be done with care to prevent lodging of the crop (Boyhan et al., 2006) and shading of prostrate crop growth (Pedreros et al., 2008). Inhibition of light transmittance appears to be the greatest factor for weed suppression by mulches (Steinmaus et al., 2008).

More research is needed before limited-input vegetable producers are able to widely adopt conservation tillage. Creative approaches to achieve adequate weed control may include the use of high-biomass winter cover crops, followed by high-biomass

summer cover crops for fall vegetable production. If summer and winter cover crops, as well as organic mulches, are chosen carefully with regard to persistence and nutrient content, it seems possible to keep land agriculturally productive while simultaneously improving soil quality.

Previous work has demonstrated the feasibility of high biomass cover crop mulches under no-tillage production systems. No-till, herbicide-free broccoli production under high biomass cover crops was shown to produce similar yields compared to conventional tillage without a cover crop in Maryland and Virginia (Abdul-Baki et al., 1997a). Such a system could achieve even greater weed suppression by using high biomass cover crops, such as forage soybean, in conjunction with organic mulches. Ideally, mulches may be grown *in situ* in order to minimize transportation costs. These mulches could be obtained from invasive species already present in the production area, such as lespedeza and mimosa cuttings, and utilized as mulch material before seeds become viable.

The objective of this study was to quantify mass loss and nutrient release rates from decomposing organic residues under conservation and conventional tillage. Information on timely release of nutrients from organic residues will help producers make informed decisions regarding residue management, including the adoption of conservation or conventional tillage.

Materials and Methods

A field decomposition study was conducted at the E.V. Smith Research Center Plant Breeding Unit (32.488ºN, 85.888ºW, 65 m elevation) in S. Tallassee, AL on a

Wickham fine sandy loam, 0 to 2 percent slopes (Fine-loamy, mixed, semiactive, thermic Typic Hapludults). The study site soil had an inital pH (1:1 soil:H_2O) of 6.3, 0.088 g N kg^{-1} soil and 1.0 g C kg^{-1} soil on a dry weight basis. Four organic residues, lespedeza (cuttings at flowering), mimosa (leaves and stems <1 cm in diameter), oat straw, and soybean (var. Stonewall, group VII), were obtained locally to supply residue. Air-dried residues were packed into nylon mesh bags measuring 20 cm x 10 cm with 50 to 60 micron openings at a rate equivalent to 6.7 Mg ha^{-1} (3.0 tons ac^{-1}) (28.3 g per bag) on an air-dry basis.

Sealed litterbags were placed on the soil surface or buried at 10 cm depth on Oct. 9, 2007. The site was maintained under no-till for at least three years prior to placement. Conventional till plots were disked immediately before placement. The treatments were arranged in a split plot design (main plot - 2 tillage systems; subplots - 4 residue types) with four replicates. Bags were periodically retrieved from the field at 0, 3.5, 7, 14, 28, 56, 112, 224, and 364 days after application. The contents of each bag were oven-dried and weighed for dry matter determination. Residues were then ground to pass a 16 mesh sieve and analyzed for total C and N by LECO TruSpec CN (Leco Corp, St. Joseph, MI). Sample contamination by soil was accounted for by converting all data to an ash-free dry weight basis by ashing approximately 1.0 gram of the samples in muffle furnace at 400^oC for 12 h and determining the ash free dry weight (AFDW) (Cochran, 1991).

Means, standard errors, and statistical significance of treatments were determined using Proc Mixed (SAS, 2003) at the 95% confidence level. Least squares estimates for nonlinear models were determined using four parameter double exponential decay models (Systat, 2008). Correlations were estimated using Proc Corr (SAS, 2003).

Results and Discussion

The double exponential decay model served as the basis for comparison of N, C, and mass loss between conservation and conventional tillage in this study. Persistence of organic residues under conservation and conventional tillage on a per area basis is shown in Figure 1. Buried residue decomposed faster than surface residue, especially in the initial, labile portion. This was evidenced by the steeper slopes in Figure 1 during the initial decomposition phase. The slopes of the recalcitrant portions, however, tended not to differ much between buried and surface residue. This indicates that labile material in particular was more resistant to decay when residue was placed on the soil surface compared to burying it.

All residues were placed at an equivalent rate of 6.7 Mg ha^{-1} on an air dry basis, but the results in Figure 1 are reported on an oven-dry basis. This accounts for the slight variation in the mass remaining at time = 0 days since different residues absorb atmospheric moisture at different rates. Sometimes it is more convenient to represent decay patterns on a percent of original material basis such that researchers can easily convert for various amount of residue in the field. For this reason, Figure 2 shows residue persistence normalized to 100 percent of initial ash-free dry weight. The parameters for the double exponential decay curve equations that were fit to the data are shown in Table 1. The difference in the rate of decay is apparent by the comparing the k_1 and k_2 values from equation 1. Buried residue exhibited faster mass loss in both the labile and recalcitrant portions of all residues, as shown by the greater rate constants k_1 and k_2 for buried material compared to surface residue (Table 1). However, the k_1 values

tended to increase faster than the k_2 values as we compared buried to surface residue, evidence again that the labile portion exhibited the greatest increase in decay when buried. Isaac et al. (2000) also showed that in environments that facilitated rapid decomposition, the labile portion of residue was more affected than the recalcitrant portion. All regression equations were significant ($p<0.02$) and were good approximations of the data (R^2_{adj}) (Table 1).

Table 2 shows the analysis of variance for mass loss on a per area basis. All effects were significant ($p<0.05$). The significant main effect and placement by residue interaction signified that not only did buried residue decompose faster than surface residue, but also that the effect varied by residue type. For example, the rate of mass loss for straw was much higher when buried compared to the other residues (Figure 1). That is, whether one residue type decomposed faster than another residue type depended on placement.

Table 3 shows the analysis of variance for mass loss for pairwise comparisons between placement of residues, holding residue constant, and also residue comparisons, holding placement constant. In all cases, the comparisons were significantly different. That is, each residue decomposed at a significantly different rate when it was buried compared to surface placed ($p<0.0001$). Similar findings have been reported elsewhere (Carter and Rennie, 1982; Skjemstad et al., 1997). Additionally, all residues decomposed at significantly different rates regardless of placement ($p<0.04$).

Carbon loss from organic residues under conservation and conventional tillage is shown in Figure 3 on an area basis and Figure 4 on a normalized basis. Since the total C contents of the residues were similar, Figure 3 and Figure 4 appear similar. However,

small differences are apparent because of variations in the total C content of any particular residue. The difference between the two representations of the data becomes apparent when comparing analysis of variance (ANOVA) values. Table 4 shows the ANOVA for all effects and interactions for mass loss on a percent basis. Although all effects were still significant ($p<0.05$), the p-value for the placement by residue interaction decreased compared to that in Table 2. Likewise, when pairwise comparisons of residue types were made, surface placed lespedeza and mimosa decay rates were not significantly different when compared on a percent basis ($p=0.7265$) (Table 5), but they were significantly different when compared on a per area basis ($p=0.0002$) (Table 3). This is simply the result of normalizing the data. The fact is that the residues did decompose at significantly different decay rates, but when the data was normalized, the effect was to bring the data points closer together, particularly as time approaches zero, thereby altering the p-values for all comparisons. The decay rate constants did not change when the data was normalized (Table 1), but the coefficients did. This "normalization effect" was also apparent on the C and N data presented in this paper.

Buried C loss models (Figure 3) appeared similar to buried mass loss models (Figure 1) because most mass loss was due to the microbial respiration of C (Wood and Edwards, 1992), which was then lost to the environment as CO_2. Conservation tillage therefore has the effect of sequestering C as SOM, compared to conventional tillage, which has the effect of respiring more soil organic carbon (SOC) as CO_2. Since there is a direct relationship between SOM and SOC, producers interested in accumulation of SOM will find that conservation tillage will ameliorate SOM content compared to conventional tillage (Balkcom et al., 2004). The results of this study imply that SOC, and by extension

SOM, will accumulate over time if applied annually. Should conservation tillage be employed over several years, the effect on SOM would be additive. That is, the accumulation of recalcitrant SOC over several years of conservation tillage would have the effect of improving the SOM content in the surface horizons. It is possible that the effect may not be noticeable after a single year, such as in the case of soybean residue, which retains less C when surface placed compared to other organic residues (Figure 3). It has been reported that after 10 years of conservation tillage, SOC concentrations were 67% higher than conventionally tilled plots (Wood and Edwards, 1992).

Buried residue exhibited faster C loss in both the labile and recalcitrant portions of all residues, as shown by the greater rate constants k_1 and k_2 for buried material compared to surface residue (Table 6). All regressions were significant ($p<0.002$) with high R^2_{adj} values (Table 6). Carbon was therefore sequestered longer when residue was left on the surface compared to residue incorporation, both for labile and recalcitrant portions of residue. This should result in greater SOM accumulation from surface residue over time. On a more speculative note, in an age when producers may be compelled to participate in a C market, conservation tillage practices may provide producers with a C offset or credit, while also enhancing SOM. If or when a monetary value is associated with C sequestration, producers utilizing conservation tillage may be able to avail themselves of the monetary benefit while simultaneously improving SOM and soil fertility.

Table 7 shows the ANOVA for C loss on a per area basis. In this case, the main effects of placement and time were both significant ($p<0.0001$), but their interaction was not ($p=0.2585$). Table 8 shows that every residue had a significantly different C loss rate

whether buried or surface placed. However, when residues were surface placed, only soybean residue lost C at a significantly higher rate than any of the other residues. In other words, lespedeza, mimosa, and oat straw all had statistically similar rates of C loss when placed on the soil surface. The effect can be seen in Figure 3. When the residues were buried, only lespedeza and straw lost C at statistically similar rates.

When the data were normalized to represent C loss on a percent of original C remaining, a different story emerged. The interaction between placement and residue was significant ($p=0.0158$) (Table 9), indicating that whether one residue type lost C at a significantly faster rate than another residue type depended on placement. In addition, only surface placed lespedeza and mimosa lost C at statistically similar rates ($p=0.7217$) (Table 10). This can be easily seen in Figure 4, where the regression lines and data points are very similar between mimosa and lespedeza. When buried, all residues lost C at different rates ($p<0.03$). As with mass loss, all residues lost C at different rates depending on whether they were surface placed or buried ($p<0.0001$) (Table 10). As expected, the rate constants did not change depending on how the data is shown, either on an area or a percent basis, but the coefficients did (Table 6). It is worth pointing out that the coefficients on a percent basis did not always add up to exactly 100. This is because the regression lines are fitted to the data, and in the attempt to model the data as closely as possible, the intercept can vary within a few percent of 100. The slight sacrifice in model accuracy near time zero should allow for a better fit of the model as time progresses compared to fixing the intercept to exactly 100.

Nitrogen loss from organic residues under conservation and conventional tillage on an area basis is shown in Figure 5. The decay equations describing the data are shown

in Table 11. Buried residue generally exhibited faster N loss in both the labile and recalcitrant portions of all residues. This is evidenced by the greater rate constants k_1 and k_2 for buried material compared to surface residue (Table 11), though notable rate constant exceptions exist in cases where the curve fit (Adj. R^2) is exceptionally low, such as in the case of straw, which had a very low original N content and negligible labile N pool. For residues with an appreciable N content, the models described the data better. All regressions were significant regardless of placement, except for straw ($p>0.9$) and surface placed mimosa ($p=0.0724$, $R^2_{adj} = 0.56$). The reason for the relatively low fit for surface placed mimosa is likely due to the outlying data point at time = 112 days. The same outlying data point can be seen in Figure 6 at time = 112 days, where N content is just above 100% of the original N contained in mimosa residue. It appears that there may have been some N immobilization occurring at that time, though it may simply have been an artifact of the data obtained in the field. Day 112 corresponds to Jan. 27, 2008, and although there was a temperature spike at that time (Figure 7), it is unclear why only one residue would have an increase in N immobilization at that time. Nitrogen immobilization is readily apparent in Figure 6, where buried straw N content reached 130% at day 28. Immobilization was dampened when straw residue was surface placed, reaching only 108% at that same time. Surface placed straw has been shown to immobilize N in Alberta, Canada as well (Soon and Arshad, 2002). The effect of N immobilization partly accounts for the poor fit of straw residue N release on a percent basis by double exponential decay models in Figure 6. However, straw N release appears to be linear when the data is expressed on an area basis (Figure 6) because the low initial N content.

Table 12 shows the ANOVA for N loss on an area basis. All effects were significant ($p<0.0001$). Table 13 shows that there was no difference in N release when straw was buried or surface placed ($p=0.9152$). All other residues released N at different rates when they were buried compared to placed on the surface ($p<0.0001$). Additionally, the pairwise comparisons between residue types were all significant ($p<0.001$) regardless of placement. That is, all residue types released N at significantly different rates compared to each other, when compared on an absolute (per area) basis. Though all effects were significant when the data were normalized ($p<0.008$) (Table 14), the pairwise comparisons were less distinct. When residues were surface placed, N from lespedeza, mimosa, and straw was released at the same rate ($p>0.39$) (Table 15) when compared on a percent basis. The only residue to release N at a significantly different rate is soybean ($p<0.0001$). This is apparent in Figure 6, where mimosa and lespedeza data were very similar. However, when residues were buried, they all released N at different rates ($p<0.0003$), even when compared on a percent basis. Straw released N at the same rate whether buried or surface placed ($p=0.7670$) (Table 15). Net N mineralization from straw was minimal (Figure 6), confirming observations of previous work (Soon and Arshad, 2002).

Table 16 shows the persistence of C, mass and N from residue under conservation or conventional tillage at various dates after placement based on decay parameters. Although caution should be applied when extrapolating data beyond the time frame of the study, two estimates of persistence at time = 3 years are provided. One estimate is an estimation of the persistence of the residue placed three years previously. The second estimate is based on the assumption that a producer may apply the residues

each year at the same time and rate. The accumulation of recalcitrant material after three years of residue application should be appreciable. For example, although buried oat straw would contain 15 kg ha^{-1} of C after three years of decomposition, yearly application would increase that value to 519 kg C ha^{-1}. When surface placed, the effect would be even greater: 580 kg C ha^{-1} versus 2877 kg C ha^{-1}, respectively. A study conducted in Alabama found that 10 years of conservation tillage resulted in approximately 8745 kg C ha^{-1} within the top 5 cm of soil (Wood and Edwards, 1992). Although the present study supports those observations, further studies are needed to confirm extrapolated results regarding the mass and nutrient residence time after extended periods.

A producer may be interested to know how much mass, C, and especially N is potentially available at spring planting, and how much of the remaining N will be mineralized over the season. Suppose that spring planting occurs on May 1, which corresponds to day 205 in this study. Table 16 shows that there remained 78 kg N ha^{-1} potentially available to spring crops from mimosa prunings on May 1, even if the residue is buried the previous fall. Under conservation tillage, the value increased to 123 kg N ha^{-1} potentially available. By the end of the season on Oct. 7, 2008, 20 kg N ha^{-1} had been mineralized from surface placed mimosa residue (Table 16). A producer may therefore elect to reduce N fertilization by an equivalent amount for a crop grown between May 1 and Oct. 7 if employing mimosa prunings as mulch under conservation tillage. Extrapolating the decay rates to the second season, from May 1 to Oct. 7, surface placed residue will release 13 kg N ha^{-1}, and in the third season, 9 kg N ha^{-1} will be mineralized from the surface placed mimosa residue. If a producer continued to apply the mulch at the same rate and same time over three years, these N release patterns

become additive, such that in the third year of production from May 1 to Oct. 7, 42 kg N ha^{-1} would be mineralized from surface placed mimosa. Similarly, surface placed lespedeza residue had 18 kg N ha^{-1} mineralized over the first season from May 1 to Oct. 7 but if lespedeza residue were placed on the surface for three consecutive years, 36 kg N ha^{-1} would be mineralized during the third growing season. That would be the same amount as soybean residue would release over the third growing season if it were applied annually.

Interestingly, the recalcitrant N pool of surface placed mimosa was greater than any other residue used in this study. At the end of a year, 51 kg N ha^{-1} had been mineralized from surface placed mimosa, or only 33% of the original N content, leaving 103 kg N ha^{-1} potentially mineralizable (Table 16). Buried mimosa residue mineralized 122 kg N ha^{-1} after one year (Figure 5), or 71% of the initial N content (Figure 6). Surface placed lespedeza behaved similarly: 46 kg N ha^{-1} was mineralized at the end of a year, or only 36% of the initial N content, leaving 83 kg N ha^{-1} potentially available to subsequent crops. These residues compared favorably to soybean residue, which lost N at a much faster rate and therefore did not have a large recalcitrant N pool. Even if soybean residue was placed year after year, by the end of three years, the N pool would be an estimated 80 kg ha^{-1}, whereas mimosa would have 218 kg N ha^{-1} and lespedeza would have 171 kg N ha^{-1}. The advantage of a recalcitrant N pool is that it may act as a slow release N fertilizer, so that larger recalcitrant N pools slowly release more N to subsequent crops.

A caveat is worth mentioning at this point: this study does not determine N fate. Though the double exponential decay model does consider the recalcitrant nature of the

remaining N residing in residue, this study does not determine the portion of mineralized N that may be plant unavailable due to leaching, volatilization, denitrification or subsequent immobilization. However, the slow release nature of recalcitrant N should improve N use efficiency in a similar manner that novel controlled release fertilizers do (Morgan et al., 2009).

Mass, C and N residence times from organic residues under conservation tillage were increased compared to conventional tillage (Table 17). A notable exception exists for N content in oat straw, for which there is no difference between conservation and conventional tillage ($p=0.9152$), as previously noted in Table 13.

Figure 9 shows the initial fiber content of the residues used in this study. Straw has a significantly higher portion of ADF, cellulose, hemicellulose, and NDF than all other residues, which, along with a low initial N content, accounts for the slower decay rates observed by straw. Correlations between residue decomposition and the initial N, C, C:N ratio, and fiber content are shown in Tables 18-23. Since different portions of the total fiber composition may be expected to decay at different rates depending on placement (Heal et al., 1997), the correlations are divided by residue type and placement. Table 18 shows correlations seven days after placement. Since correlations were highly variable, it is difficult to make generalizations regarding fiber analyses and any particular decay parameter. However, C decay was generally negatively correlated with initial ADL seven days after placement (Table 18), but that correlation became less apparent as time progressed (Tables 19-23). Generally speaking, the best correlations of C decay seven days after placement occurred with initial hemicellulose (Table 18). Nitrogen decay generally correlated best with initial cellulose and NDF, while that of mass

occurred with C and hemicellulose. Fourteen days after placement, mass, C and N all correlated well with initial hemicellulose and NDF content (Table 19) and reasonably well with initial cellulose content. In addition, C decay correlated well with initial polyphenol content, while N decay correlated very well with ADL. After 28 days in the field, residues correlated less well with initial hemicellulose content (Table 20), and better with initial polyphenol content. This is generally true for correlations of residues retrieved up to, and including, 112 days after placement (Tables 21-23). This seems reasonable since hemicellulose is metabolized faster than tannins (Handayanto et al., 1997).

The negative correlation between the mass of buried straw 28 days after placement (Table 20) with initial ADL (-0.610) closely resembled that observed in the laboratory by Stubbs et al. (2009) (correlation = -0.600), though that study correlated the parameters based on ADL at the time of sampling, not initial sampling. Similarly, the correlations between the mass of buried straw 28 days after placement with initial C and C:N (0.062 and -0.285, respectively) closely resembled that observed by Stubbs et al. (2009) (0.108 and -0.332, respectively) 28 days after placement. By comparison, the mass of buried straw 56 days after placement (Table 21) was correlated to initial N and C:N (0.528 and -0.605, respectively) (Table 21), while Stubbs et al. (2009) found correlations of 0.208 and -0.332, respectively. By 112 days after placement (Table 22), buried straw mass correlations with ADF (-0.588), ADL (-0.601), C (0.473), N (0.676), and C:N (-0.815) were in excellent agreement with those reported by Stubbs et al. (2009): -0.497, -0.400, 0.378, 0.277, and -0.379, respectively.

A few notes regarding the methodology are warranted. It seems possible that decay rates for buried residue are underestimated using litterbag methodology, a possibility also noted by Wieder and Lang (1982). When residues are incorporated during conventional tillage, the residue is distributed more uniformly in the surface horizons, with more intimate soil contact. That intimate contact with the soil may have a greater effect on residue decomposition because more surface area is exposed to microbial activity. Additionally, the efficiency of synchronicity is reduced when nutrient supplies are evenly distributed in the soil (Myers et al., 1997). On the other hand, litterbag methodology may have the effect of increasing labile decomposition because of the increased oxygen content surrounding the residue within the litterbag. The additional oxygen supply, however, can be expected to become rapidly depleted and should not have an appreciable effect on recalcitrant decomposition. By contrast, the decay rates for surface placed residue using litterbag methodology should be representative of actual field decomposition under conservation tillage.

Conclusions

Buried residues decompose faster and release C and N quicker than surface residues, but the effect is greater in the labile portion than the recalcitrant portion. Labile material in particular is more resistant to decay when residue is placed on the soil surface compared to burying it. Buried C loss models are very similar to buried mass loss models because most mass is lost through microbial respiration of organic C. Organic C is sequestered for longer periods when residue is left on the soil surface, as in conservation tillage, compared to burying the residue, as in conventional tillage. Surface

placed residual mass and C decayed in the order soybean > mimosa > lespedeza > straw. When buried, residual mass and C decay occurred in the order soybean > mimosa > lespedeza, with straw decomposition intersecting mimosa and lespedeza decay models at various points depending on time. Although soybean had the highest initial N content, it decayed quickly such that both mimosa and lespedeza had higher N contents per hectare within two weeks when buried and around 50 d when surface placed. Caution should be used when interpreting results on a relative basis because some residues may not appear to decay differently, when in fact they have entirely different decay rates on an absolute basis. Double exponential decay equations describe both surface and buried residue decay data well, except when N immobilization occurs or when residues have a low N content. Surface residues may act as a slow release N fertilizer and contribute to organic matter accumulation on the soil surface, particularly if residues are applied annually. This study demonstrates that *in situ* cover crops and mulches may be utilized for the enhancement of SOM and soil N status. Further studies need to be conducted in order to determine if the decay rates remain valid for extended periods of time.

Table 1. Equations regressed on time (days) for mass loss from mulches incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Species	Equation	$P>F^{\dagger}$	$R^2_{adj.}$	$S_{yx}^{\ddagger}$
Mass buried (Mg ha^{-1})				
Lespedeza cuneata	$Y = 2.07e^{-0.1061X} + 4.44e^{-0.0020X}$	<0.0001	0.990	0.1
Albizia julibrissin§	$Y = 2.64e^{-0.0890X} + 3.67e^{-0.0018X}$	<0.0001	0.981	0.2
Avena sativa straw	$Y = 1.29e^{-0.0719X} + 5.24e^{-0.0034X}$	<0.0001	0.997	0.1
Glycine max	$Y = 3.93e^{-0.1063X} + 2.43e^{-0.0022X}$	0.0004	0.947	0.4
Mass surface (Mg ha^{-1})				
Lespedeza cuneata	$Y = 1.28e^{-0.0761X} + 5.20e^{-0.0012X}$	0.0002	0.959	0.2
Albizia julibrissin§	$Y = 1.34e^{-0.0428X} + 4.81e^{-0.0015X}$	0.0002	0.957	0.2
Avena sativa straw	$Y = 1.25e^{-0.0459X} + 5.20e^{-0.0007X}$	0.0129	0.784	0.4
Glycine max	$Y = 2.96e^{-0.0385X} + 3.42e^{-0.0019X}$	<0.0001	0.987	0.2
Mass buried (% remaining)				
Lespedeza cuneata	$Y = 32.2e^{-0.1061X} + 69.2e^{-0.0020X}$	<0.0001	0.990	2.3
Albizia julibrissin§	$Y = 42.0e^{-0.0890X} + 58.4e^{-0.0018X}$	<0.0001	0.981	3.3
Avena sativa straw	$Y = 20.0e^{-0.0719X} + 81.3e^{-0.0034X}$	<0.0001	0.997	1.4
Glycine max	$Y = 64.3e^{-0.1063X} + 39.8e^{-0.0022X}$	0.0004	0.947	6.9
Mass surface (% remaining)				
Lespedeza cuneata	$Y = 20.0e^{-0.0761X} + 81.3e^{-0.0012X}$	0.0002	0.959	3.4
Albizia julibrissin§	$Y = 22.2e^{-0.0428X} + 79.7e^{-0.0015X}$	0.0002	0.957	4.1
Avena sativa straw	$Y = 19.8e^{-0.0459X} + 82.2e^{-0.0007X}$	0.0129	0.784	6.6
Glycine max	$Y = 47.7e^{-0.0385X} + 55.3e^{-0.0019X}$	<0.0001	0.987	3.2

† Significance of regression; ‡ Standard error of the estimate of Y on X; § Stems < 1 cm in diameter.

Table 2. Analysis of variance for mass loss on an area basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	0.0444
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	<0.0001

Table 3. Mass loss analysis of variance for pairwise comparisons between placement and residue types on an area basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	<0.0001
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	<0.0001
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	0.0002
Surface	*Lespedeza cuneata*	*Avena sativa* straw	0.0003
Surface	*Lespedeza cuneata*	*Glycine max*	<0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Surface	*Albizia julibrissin*	*Glycine max*	<0.0001
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	<0.0001
Buried	*Lespedeza cuneata*	*Avena sativa* straw	0.0390
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 4. Mass loss analysis of variance on a percent basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	0.0353
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	<0.0001

Table 5. Mass loss analysis of variance for pairwise comparisons between placement and residue types on a percent basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	<0.0001
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	<0.0001
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	0.7265
Surface	*Lespedeza cuneata*	*Avena sativa* straw	<0.0001
Surface	*Lespedeza cuneata*	*Glycine max*	<0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Surface	*Albizia julibrissin*	*Glycine max*	<0.0001
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	<0.0001
Buried	*Lespedeza cuneata*	*Avena sativa* straw	0.0959
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 6. Equations regressed on time (days) for carbon loss from mulches incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Species	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
C buried (kg ha^{-1})				
Lespedeza cuneata	$Y = 673.8e^{-0.1173X} + 1980.4e^{-0.0029X}$	<0.0001	0.985	78.9
Albizia julibrissin§	$Y = 906.6e^{-0.1006X} + 1754.4e^{-0.0030X}$	<0.0001	0.997	38.5
Avena sativa straw	$Y = 210.2e^{-0.0952X} + 2276.1e^{-0.0046X}$	<0.0001	0.991	71.2
Glycine max	$Y = 1328.0e^{-0.1178X} + 1048.8e^{-0.0039X}$	0.0004	0.947	166
C surface (kg ha^{-1})				
Lespedeza cuneata	$Y = 257.0e^{-0.0911X} + 2373.3e^{-0.0018X}$	0.0005	0.942	116
Albizia julibrissin§	$Y = 274.4e^{-0.0461X} + 2291.0e^{-0.0020X}$	0.0002	0.960	103
Avena sativa straw	$Y = 288.9e^{-0.0280X} + 2162.6e^{-0.0012X}$	0.0014	0.913	116
Glycine max	$Y = 1030.5e^{-0.0298X} + 1313.1e^{-0.0021X}$	<0.0001	0.978	95.9
C buried (% remaining)				
Lespedeza cuneata	$Y = 25.8e^{-0.1173X} + 75.8e^{-0.0029X}$	<0.0001	0.985	3.0
Albizia julibrissin§	$Y = 34.2e^{-0.1006X} + 66.2e^{-0.0030X}$	<0.0001	0.997	1.5
Avena sativa straw	$Y = 8.6e^{-0.0952X} + 93.0e^{-0.0046X}$	<0.0001	0.991	2.9
Glycine max	$Y = 58.2e^{-0.1178X} + 46.0e^{-0.0039X}$	0.0004	0.947	7.3
C surface (% remaining)				
Lespedeza cuneata	$Y = 9.9e^{-0.0911X} + 91.5e^{-0.0018X}$	0.0005	0.942	4.5
Albizia julibrissin§	$Y = 11.0e^{-0.0461X} + 91.7e^{-0.0020X}$	0.0002	0.960	4.1
Avena sativa straw	$Y = 12.1e^{-0.0280X} + 90.8e^{-0.0012X}$	0.0014	0.913	4.9
Glycine max	$Y = 45.5e^{-0.0298X} + 57.9e^{-0.0021X}$	<0.0001	0.978	4.2

† Significance of regression; ‡ Standard error of the estimate of Y on X; § Stems < 1 cm in diameter.

Table 7. Carbon loss analysis of variance on an area basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	0.2585
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	<0.0001

Table 8. Carbon loss analysis of variance for pairwise comparisons between placement and residue types on an area basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	<0.0001
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	<0.0001
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	0.0569
Surface	*Lespedeza cuneata*	*Avena sativa* straw	0.1534
Surface	*Lespedeza cuneata*	*Glycine max*	<0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	0.5859
Surface	*Albizia julibrissin*	*Glycine max*	<0.0001
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	0.0008
Buried	*Lespedeza cuneata*	*Avena sativa* straw	0.2942
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	0.0212
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 9. Analysis of variance for carbon loss on a percent basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	0.0158
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	<0.0001

Table 10. Carbon loss analysis of variance for pairwise comparisons between placement and residue types on a percent basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	<0.0001
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	<0.0001
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	0.7217
Surface	*Lespedeza cuneata*	*Avena sativa* straw	0.0001
Surface	*Lespedeza cuneata*	*Glycine max*	<0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	0.0010
Surface	*Albizia julibrissin*	*Glycine max*	<0.0001
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	0.0002
Buried	*Lespedeza cuneata*	*Avena sativa* straw	0.0207
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 11. Equations regressed on time (days) for nitrogen loss from mulches incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where *Y* = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and *t* = time in days after application.

Parameter/Species	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
N buried (kg ha^{-1})				
Lespedeza cuneata	$Y = 61.9e^{-0.0028X} + 65.5e^{-0.0028X}$	0.0010	0.923	8.3
Albizia julibrissin§	$Y = 40.3e^{-0.3053X} + 132.6e^{-0.0026X}$	0.0010	0.922	10.7
Avena sativa straw	$Y = 8.4e^{-0.0005X} + 18.0e^{-0.0005X}$	0.9156	0.000	6.2
Glycine max	$Y = 104.4e^{-0.0873X} + 76.2e^{-0.0033X}$	0.0007	0.935	14.2
N surface (kg ha^{-1})				
Lespedeza cuneata	$Y = 61.9e^{-0.0012X} + 66.9e^{-0.0012X}$	0.0047	0.857	6.3
Albizia julibrissin§	$Y = 74.4e^{-0.0011X} + 79.3e^{-0.0011X}$	0.0724	0.560	13.8
Avena sativa straw	$Y = 44.4e^{-0.0014X} - 20.6e^{-0.0053X}$	0.9008	0.000	4.3
Glycine max	$Y = 68.2e^{-0.0239X} + 114.0e^{-0.0023X}$	0.0003	0.956	10.4
N buried (% remaining)				
Lespedeza cuneata	$Y = 47.3e^{-0.0028X} + 50.1e^{-0.0028X}$	0.0010	0.923	6.4
Albizia julibrissin§	$Y = 23.4e^{-0.3053X} + 77.0e^{-0.0026X}$	0.0010	0.922	6.2
Avena sativa straw	$Y = 29.7e^{-0.0005X} + 63.2e^{-0.0005X}$	0.9156	0.000	21.9
Glycine max	$Y = 62.0e^{-0.0873X} + 45.2e^{-0.0033X}$	0.0007	0.935	8.4
N surface (% remaining)				
Lespedeza cuneata	$Y = 45.9e^{-0.0012X} + 49.6e^{-0.0012X}$	0.0047	0.857	4.7
Albizia julibrissin§	$Y = 47.3e^{-0.0011X} + 50.5e^{-0.0011X}$	0.0724	0.560	8.8
Avena sativa straw	$Y = 157.1e^{-0.0014X} - 72.8e^{-0.0053X}$	0.9008	0.000	15.4
Glycine max	$Y = 39.1e^{-0.0239X} + 65.4e^{-0.0023X}$	0.0003	0.956	6.0

† Significance of regression; ‡ Standard error of the estimate of Y on X; § Stems < 1 cm in diameter.

Table 12. Nitrogen loss analysis of variance on an area basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	<0.0001
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	<0.0001

Table 13. Nitrogen loss analysis of variance for pairwise comparisons between placement and residue types on an area basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	<0.0001
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	0.9152
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	<0.0001
Surface	*Lespedeza cuneata*	*Avena sativa* straw	<0.0001
Surface	*Lespedeza cuneata*	*Glycine max*	0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Surface	*Albizia julibrissin*	*Glycine max*	0.0009
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	0.0001
Buried	*Lespedeza cuneata*	*Avena sativa* straw	<0.0001
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 14. Nitrogen loss analysis of variance on percent basis.

Effect	P>F
Residue	<0.0001
Placement	<0.0001
Placement x Residue	<0.0001
Time	<0.0001
Time x Placement	<0.0001
Time x Residue	<0.0001
Time x Placement x Residue	0.0073

Table 15. Nitrogen loss analysis of variance for pairwise comparisons between placement and residue types on a percent basis.

Residue	**Placement comparison**		**P>F**
Lespedeza cuneata	Surface	Buried	0.0047
Albizia julibrissin	Surface	Buried	<0.0001
Avena sativa straw	Surface	Buried	0.7670
Glycine max	Surface	Buried	<0.0001

Placement	**Residue comparison**		**P>F**
Surface	*Lespedeza cuneata*	*Albizia julibrissin*	0.3932
Surface	*Lespedeza cuneata*	*Avena sativa* straw	0.5024
Surface	*Lespedeza cuneata*	*Glycine max*	<0.0001
Surface	*Albizia julibrissin*	*Avena sativa* straw	0.8310
Surface	*Albizia julibrissin*	*Glycine max*	<0.0001
Surface	*Avena sativa* straw	*Glycine max*	<0.0001
Buried	*Lespedeza cuneata*	*Albizia julibrissin*	<0.0001
Buried	*Lespedeza cuneata*	*Avena sativa* straw	0.0002
Buried	*Lespedeza cuneata*	*Glycine max*	<0.0001
Buried	*Albizia julibrissin*	*Avena sativa* straw	<0.0001
Buried	*Albizia julibrissin*	*Glycine max*	<0.0001
Buried	*Avena sativa* straw	*Glycine max*	<0.0001

Table 16. Persistence of carbon, mass and nitrogen from 6.7 Mg ha^{-1} residue under conservation or conventional tillage at various dates after placement based on decay parameters.

Date	Days†	*Lespedeza cuneata*	*Albizia julibrissin*‡	*Avena sativa* straw	*Glycine max*
		C buried (kg ha^{-1})			
10/9/2007	0	2654	2661	2486	2377
5/1/2008	205	1093	949	886	471
10/7/2008	364	689	589	427	254
10/9/2010§	1096	82	65	15	15
10/9/2010§¥	1096	1008	849	519	328
		C surface (kg ha^{-1})			
10/9/2007	0	2630	2565	2451	2344
5/1/2008	205	1641	1520	1692	856
10/7/2008	364	1233	1106	1397	611
10/9/2010§	1096	330	256	580	131
10/9/2010§¥	1096	2198	1892	2877	1025
		Mass buried (Mg ha^{-1})			
10/9/2007	0	6.5	6.3	6.5	6.4
5/1/2008	205	2.9	2.5	2.6	1.5
10/7/2008	364	2.1	1.9	1.5	1.1
10/9/2010§	1096	0.5	0.5	0.1	0.2
10/9/2010§¥	1096	3.7	3.4	2.1	1.8
		Mass surface (Mg ha^{-1})			
10/9/2007	0	6.5	6.1	6.5	6.4
5/1/2008	205	4.1	3.5	4.5	2.3
10/7/2008	364	3.4	2.8	4.0	1.7
10/9/2010§	1096	1.4	0.9	2.4	0.4
10/9/2010§¥	1096	6.9	5.3	9.6	3.0
		N buried (kg ha^{-1})			
10/9/2007	0	127	173	26	181
5/1/2008	205	72	78	24	39
10/7/2008	364	46	51	22	23
10/9/2010§	1096	6	8	15	2
10/9/2010§¥	1096	68	79	56	32
		N surface (kg ha^{-1})			
10/9/2007	0	129	154	24	182
5/1/2008	205	101	123	26	72
10/7/2008	364	83	103	24	49
10/9/2010§	1096	35	46	10	9
10/9/2010§¥	1096	171	218	49	80

† Days after residue placement; ‡ Stems < 1 cm in diameter; § Extrapolated data to time = 3 years; ¥ Assuming residues were placed at the same rate and date each year for 3 years.

Table 17. Carbon, mass and nitrogen increase from residue under conservation tillage over that of conventional tillage at various dates after placement based on decay parameters. Residues were applied at a rate of 6.7 Mg ha^{-1}

Date	Days†	*Lespedeza cuneata*	*Albizia julibrissin*‡	*Avena sativa* straw	*Glycine max*
			C (kg ha^{-1})		
5/1/2008	205	548	572	805	385
10/7/2008	364	543	518	971	358
10/9/2010§	1096	248	190	566	117
10/9/2010§¥	1096	1190	1043	2358	697
			Mass (Mg ha^{-1})		
5/1/2008	205	1.1	1.0	1.9	0.8
10/7/2008	364	1.2	0.9	2.5	0.6
10/9/2010§	1096	0.9	0.4	2.3	0.2
10/9/2010§¥	1096	3.2	1.9	7.5	1.2
			N (kg ha^{-1})		
5/1/2008	205	29	45	3	33
10/7/2008	364	37	52	2	26
10/9/2010§	1096	29	38	-6	7
10/9/2010§¥	1096	103	139	-7	48

† Days after residue placement; ‡ Stems < 1 cm in diameter; § Extrapolated data to time = 3 years; ¥ Assuming residues were placed at the same rate and date each year for 3 years.

Table 18. Pearson correlation of initial fiber analyses to residue decomposition parameters 7 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	0.422	0.330	-0.122	0.459	-0.036	0.112	0.143	0.868	-0.869	0.555
L. cuneata	Buried	-0.675	-0.851	0.922	-0.080	-0.956	-0.878	0.542	0.460	-0.448	-0.139
A. julibrissin	Surface	0.132	-0.204	0.611	0.008	-0.503	-0.851	-0.721	-0.284	0.253	0.171
A. julibrissin	Buried	-0.805	-0.069	-0.584	0.331	-0.589	0.539	-0.686	-0.189	0.179	-0.462
A. sativa straw	Surface	-0.752	-0.808	0.865	-0.670	-0.999	0.734	-0.259	0.981	-0.995	-0.523
A. sativa straw	Buried	0.862	0.181	0.988	0.298	-0.152	0.053	0.208	0.567	-0.490	0.445
Glycine max	Surface	-0.157	-0.043	-0.580	-0.012	0.174	-0.737	-0.027	0.301	-0.140	0.894
Glycine max	Buried	-0.595	-0.153	-0.883	-0.021	-0.579	-0.598	0.658	0.025	-0.148	-0.909
					N						
L. cuneata	Surface	0.712	0.653	-0.460	0.494	0.287	0.038	0.047	0.679	-0.678	0.211
L. cuneata	Buried	-0.605	-0.372	-0.281	-0.869	-0.103	-0.323	0.111	-0.403	0.508	0.617
A. julibrissin	Surface	-0.440	-0.156	-0.479	-0.357	0.181	0.977	0.911	-0.023	0.089	-0.044
A. julibrissin	Buried	0.510	0.498	-0.211	0.547	0.275	-0.810	0.400	0.547	-0.358	0.993
A. sativa straw	Surface	-0.724	-0.783	0.843	-0.639	-0.996	0.762	-0.219	0.989	-0.998	-0.487
A. sativa straw	Buried	-0.134	-0.716	0.385	-0.843	0.473	-0.953	0.713	-0.411	0.585	0.198
Glycine max	Surface	0.869	0.796	0.853	0.779	0.804	0.628	-0.634	0.083	-0.158	-0.448
Glycine max	Buried	0.697	0.462	0.447	0.362	0.911	0.256	-0.521	0.287	-0.242	0.487
					Mass						
L. cuneata	Surface	0.483	0.317	0.023	0.056	0.161	0.508	0.530	0.939	-0.938	0.521
L. cuneata	Buried	-0.599	-0.790	0.918	0.028	-0.926	-0.824	0.491	0.465	-0.466	-0.225
A. julibrissin	Surface	-0.396	-0.057	-0.585	-0.158	0.149	-0.297	0.016	0.413	-0.222	0.947
A. julibrissin	Buried	-0.831	-0.128	-0.529	0.264	-0.613	0.560	-0.713	-0.247	0.228	-0.520
A. sativa straw	Surface	-0.768	-0.822	0.877	-0.689	-1.000	0.717	-0.283	0.976	-0.992	-0.544
A. sativa straw	Buried	0.028	-0.737	0.613	-0.534	0.036	-0.723	0.893	-0.372	0.495	0.618
Glycine max	Surface	-0.518	-0.395	-0.843	-0.362	-0.206	-0.917	0.277	0.177	-0.006	0.945
Glycine max	Buried	-0.549	-0.092	-0.918	0.040	-0.504	-0.618	0.646	0.080	-0.209	-0.935

Table 19. Pearson correlation of initial fiber analyses to residue decomposition parameters 14 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	-0.721	-0.780	0.781	-0.770	-0.317	0.420	0.425	-0.242	0.243	0.137
L. cuneata	Buried	0.216	-0.092	0.737	0.254	-0.204	-0.094	0.630	0.935	-0.969	0.045
A. julibrissin	Surface	0.680	0.191	0.833	0.432	-0.244	-0.579	-0.768	-0.279	0.078	-0.696
A. julibrissin	Buried	-0.972	-0.988	0.999	-0.944	-0.862	0.210	-0.924	-0.990	0.931	-0.783
A. sativa straw	Surface	0.980	0.958	-0.923	0.996	0.646	0.098	0.926	-0.440	0.523	0.995
A. sativa straw	Buried	0.993	0.676	0.772	0.467	0.105	0.315	-0.374	0.928	-0.861	-0.084
Glycine max	Surface	-0.481	-0.522	-0.125	-0.536	-0.701	0.151	0.467	-0.307	0.230	-0.407
Glycine max	Buried	0.342	-0.083	0.863	-0.208	0.505	0.242	-0.336	-0.273	0.353	0.707
					N						
L. cuneata	Surface	0.966	0.934	-0.750	0.301	0.713	0.077	0.053	0.336	-0.333	-0.277
L. cuneata	Buried	-0.401	-0.637	0.919	-0.354	-0.606	-0.614	0.954	0.906	-0.867	0.440
A. julibrissin	Surface	-0.269	-0.529	0.515	-0.366	-0.696	-0.623	-0.396	-0.455	0.499	0.442
A. julibrissin	Buried	-0.942	-0.913	0.862	-0.611	-0.999	-0.358	-0.983	-0.906	0.979	-0.316
A. sativa straw	Surface	0.925	0.955	-0.981	0.875	0.962	-0.475	0.558	-0.867	0.910	0.771
A. sativa straw	Buried	0.539	-0.106	0.789	-0.414	0.535	-0.590	0.279	0.297	-0.103	0.019
Glycine max	Surface	-0.268	-0.402	0.401	-0.435	-0.570	0.351	0.497	-0.693	0.577	-0.818
Glycine max	Buried	-0.120	-0.020	-0.200	-0.016	0.378	-0.711	0.440	-0.087	-0.020	-0.459
					Mass						
L. cuneata	Surface	-0.318	-0.288	0.196	-0.694	0.189	0.181	0.146	-0.727	0.730	-0.532
L. cuneata	Buried	0.557	0.276	0.447	0.632	0.081	0.252	0.230	0.700	-0.779	-0.285
A. julibrissin	Surface	0.863	0.480	0.614	0.663	0.090	-0.417	-0.698	-0.026	-0.199	-0.873
A. julibrissin	Buried	-0.875	-0.910	0.951	-0.998	-0.695	0.463	-0.789	-0.917	0.800	-0.921
A. sativa straw	Surface	0.976	0.953	-0.917	0.995	0.634	0.113	0.932	-0.427	0.510	0.997
A. sativa straw	Buried	0.781	0.396	0.714	-0.085	0.586	-0.214	-0.222	0.705	-0.541	-0.307
Glycine max	Surface	-0.571	-0.626	-0.118	-0.642	-0.788	0.064	0.595	-0.452	0.385	-0.425
Glycine max	Buried	0.468	0.008	0.927	-0.113	0.273	0.753	-0.672	-0.125	0.276	0.991

Table 20. Pearson correlation of initial fiber analyses to residue decomposition parameters 28 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	0.426	0.612	-0.860	0.820	0.205	-0.837	-0.857	-0.397	0.395	-0.501
L. cuneata	Buried	0.683	0.599	-0.190	-0.026	0.702	0.649	0.268	0.482	-0.486	0.504
A. julibrissin	Surface	-0.632	-0.595	0.002	-0.694	-0.360	0.939	0.899	-0.553	0.597	-0.103
A. julibrissin	Buried	0.793	0.243	0.351	-0.337	0.838	0.217	0.817	0.324	-0.469	-0.032
A. sativa straw	Surface	0.760	0.699	-0.621	0.830	0.196	0.567	0.993	0.049	0.046	0.919
A. sativa straw	Buried	-0.150	-0.847	0.467	-0.592	-0.009	-0.753	0.952	-0.535	0.640	0.642
Glycine max	Surface	0.867	0.771	0.944	0.748	0.724	0.779	-0.604	0.021	-0.131	-0.638
Glycine max	Buried	-0.807	-0.988	0.424	-0.999	-0.687	-0.463	0.660	-0.999	0.985	-0.027
					N						
L. cuneata	Surface	0.641	0.487	-0.146	-0.663	0.812	0.807	0.772	0.238	-0.231	-0.295
L. cuneata	Buried	0.414	0.627	-0.862	-0.265	0.827	0.674	-0.344	-0.437	0.467	0.419
A. julibrissin	Surface	0.438	0.576	-0.308	0.469	0.641	0.522	0.236	0.375	-0.473	-0.648
A. julibrissin	Buried	0.653	0.378	0.062	0.296	0.381	-0.854	0.518	0.459	-0.301	0.940
A. sativa straw	Surface	0.974	0.950	-0.913	0.994	0.627	0.122	0.935	-0.418	0.502	0.997
A. sativa straw	Buried	-0.650	0.141	-0.963	0.124	-0.104	0.366	-0.451	-0.301	0.161	-0.417
Glycine max	Surface	0.042	0.198	-0.638	0.235	0.357	-0.502	-0.343	0.695	-0.562	0.937
Glycine max	Buried	0.465	0.556	-0.217	0.578	0.009	0.731	-0.622	0.641	-0.568	0.239
					Mass						
L. cuneata	Surface	0.427	0.612	-0.861	0.820	0.206	-0.836	-0.857	-0.398	0.396	-0.502
L. cuneata	Buried	0.221	0.136	0.101	-0.480	0.337	0.207	0.661	0.644	-0.593	0.845
A. julibrissin	Surface	-0.625	-0.615	0.053	-0.702	-0.399	0.922	0.877	-0.593	0.629	-0.127
A. julibrissin	Buried	0.961	0.513	0.148	-0.033	0.956	-0.003	0.967	0.599	-0.677	0.331
A. sativa straw	Surface	0.876	0.830	-0.767	0.926	0.391	0.388	0.996	-0.155	0.247	0.980
A. sativa straw	Buried	-0.498	0.100	-0.731	0.467	-0.610	0.624	-0.239	-0.285	0.084	0.062
Glycine max	Surface	0.783	0.669	0.973	0.642	0.622	0.741	-0.480	-0.128	0.016	-0.704
Glycine max	Buried	-0.889	-0.871	0.016	-0.820	-0.985	-0.369	0.668	-0.770	0.745	-0.260

Table 21. Pearson correlation of initial fiber analyses to residue decomposition parameters 56 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	0.818	0.818	-0.709	0.598	0.426	-0.165	-0.171	0.419	-0.418	-0.069
L. cuneata	Buried	0.808	0.896	-0.753	0.740	0.760	0.861	-0.875	-0.537	0.449	-0.595
A. julibrissin	Surface	-0.668	-0.791	0.306	-0.715	-0.777	-0.244	0.047	-0.558	0.678	0.661
A. julibrissin	Buried	0.736	0.704	-0.285	0.226	0.926	0.494	0.854	0.728	-0.861	0.067
A. sativa straw	Surface	0.283	0.196	-0.093	0.392	-0.371	0.924	0.768	0.586	-0.507	0.554
A. sativa straw	Buried	-0.840	-0.300	-0.866	-0.605	0.470	-0.381	-0.113	-0.588	0.590	-0.556
Glycine max	Surface	0.812	0.848	0.350	0.857	0.946	0.270	-0.804	0.547	-0.534	0.188
Glycine max	Buried	-0.877	-0.688	-0.340	-0.597	-0.977	-0.459	0.720	-0.536	0.475	-0.530
					N						
L. cuneata	Surface	-0.493	-0.327	-0.014	0.784	-0.723	-0.878	-0.846	-0.221	0.214	0.233
L. cuneata	Buried	-0.713	-0.598	0.121	-0.996	-0.318	-0.537	0.546	0.044	0.074	0.824
A. julibrissin	Surface	-0.930	-0.922	0.092	-0.939	-0.742	0.214	0.494	-0.606	0.768	0.689
A. julibrissin	Buried	0.693	-0.090	0.693	-0.605	0.608	-0.092	0.638	0.016	-0.121	-0.011
A. sativa straw	Surface	-0.795	-0.738	0.664	-0.860	-0.250	-0.520	-0.998	0.007	-0.101	-0.939
A. sativa straw	Buried	-0.400	0.322	-0.777	0.502	-0.434	0.691	-0.493	-0.095	-0.093	-0.195
Glycine max	Surface	0.662	0.752	0.029	0.773	0.872	0.066	-0.783	0.727	-0.675	0.482
Glycine max	Buried	0.891	0.584	0.585	0.472	0.842	0.713	-0.867	0.428	-0.317	0.802
					Mass						
L. cuneata	Surface	0.925	0.980	-0.948	0.459	0.718	-0.249	-0.284	-0.024	0.027	-0.543
L. cuneata	Buried	0.965	0.981	-0.650	0.468	0.960	0.989	-0.437	-0.087	0.027	-0.079
A. julibrissin	Surface	-0.649	-0.823	0.399	-0.728	-0.838	-0.232	0.036	-0.637	0.740	0.580
A. julibrissin	Buried	0.794	0.763	-0.311	0.292	0.956	0.399	0.899	0.792	-0.902	0.183
A. sativa straw	Surface	0.268	0.181	-0.078	0.378	-0.385	0.930	0.758	0.598	-0.520	0.541
A. sativa straw	Buried	-0.885	-0.226	-0.984	-0.315	0.130	-0.074	-0.161	-0.605	0.528	-0.405
Glycine max	Surface	0.832	0.859	0.402	0.866	0.951	0.308	-0.804	0.515	-0.510	0.133
Glycine max	Buried	-0.591	-0.281	-0.609	-0.169	-0.807	-0.244	0.463	-0.093	0.036	-0.574

Table 22. Pearson correlation of initial fiber analyses to residue decomposition parameters 112 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	-0.320	-0.485	0.715	-0.102	-0.536	0.477	0.532	0.885	-0.887	0.962
L. cuneata	Buried	0.904	0.978	-0.776	0.640	0.893	0.962	-0.750	-0.406	0.328	-0.395
A. julibrissin	Surface	0.859	0.906	-0.935	0.833	0.953	0.395	0.341	0.820	-0.852	-0.186
A. julibrissin	Buried	0.563	0.064	0.388	-0.483	0.680	0.458	0.621	0.123	-0.316	-0.347
A. sativa straw	Surface	0.823	0.770	-0.699	0.884	0.297	0.478	1.000	-0.055	0.149	0.955
A. sativa straw	Buried	-0.549	-0.198	-0.565	0.380	-0.784	0.472	0.127	-0.488	0.294	0.410
Glycine max	Surface	-0.740	-0.766	-0.351	-0.774	-0.888	-0.174	0.700	-0.427	0.401	-0.197
Glycine max	Buried	-0.899	-0.590	-0.588	-0.483	-0.723	-0.869	0.952	-0.460	0.328	-0.874
					N						
L. cuneata	Surface	0.048	-0.051	0.221	0.413	-0.393	0.107	0.157	0.910	-0.912	0.823
L. cuneata	Buried	-0.650	-0.627	0.343	0.126	-0.773	-0.684	-0.187	-0.330	0.322	-0.568
A. julibrissin	Surface	-0.267	-0.170	0.094	-0.314	-0.040	0.990	0.997	-0.336	0.280	-0.997
A. julibrissin	Buried	0.141	0.340	-0.317	0.041	0.469	0.937	0.324	0.302	-0.500	-0.530
A. sativa straw	Surface	0.979	0.957	-0.922	0.996	0.645	0.099	0.927	-0.439	0.522	0.995
A. sativa straw	Buried	0.855	0.917	0.403	0.529	0.238	0.488	-0.751	0.990	-0.957	-0.462
Glycine max	Surface	-0.425	-0.538	0.211	-0.565	-0.701	0.216	0.594	-0.669	0.573	-0.691
Glycine max	Buried	0.582	0.198	0.764	0.096	0.261	0.918	-0.814	0.104	0.055	0.972
					Mass						
L. cuneata	Surface	0.315	0.262	-0.132	-0.785	0.739	0.532	0.479	-0.406	0.412	-0.667
L. cuneata	Buried	0.834	0.836	-0.530	0.131	0.919	0.875	-0.106	0.134	-0.155	0.308
A. julibrissin	Surface	0.889	0.930	-0.956	0.866	0.970	0.337	0.282	0.854	-0.883	-0.125
A. julibrissin	Buried	0.430	-0.101	0.488	-0.611	0.544	0.482	0.481	-0.047	-0.156	-0.478
A. sativa straw	Surface	0.860	0.811	-0.746	0.913	0.360	0.418	0.999	-0.122	0.215	0.972
A. sativa straw	Buried	-0.793	-0.588	-0.579	-0.038	-0.601	0.046	0.450	-0.815	0.676	0.473
Glycine max	Surface	-0.546	-0.583	-0.185	-0.595	-0.750	0.075	0.523	-0.330	0.265	-0.356
Glycine max	Buried	-0.739	-0.535	-0.379	-0.473	-0.330	-0.996	0.926	-0.500	0.359	-0.776

Table 23. Pearson correlation of initial fiber analyses to residue decomposition parameters 224 days after placement.

Residue	Placement	NDF	ADF	HC	Cellulose	ADL	AIA	Polyphenol	C:N	N	C
					C						
L. cuneata	Surface	0.827	0.911	-0.939	0.646	0.547	-0.423	-0.449	-0.014	0.015	-0.446
L. cuneata	Buried	-0.587	-0.698	0.683	0.200	-0.884	-0.754	0.118	0.091	-0.110	-0.518
A. julibrissin	Surface	-0.273	-0.367	0.437	-0.225	-0.485	-0.918	-0.893	-0.202	0.259	0.810
A. julibrissin	Buried	0.962	0.661	-0.041	0.301	0.839	-0.424	0.912	0.746	-0.700	0.778
A. sativa straw	Surface	0.177	0.263	-0.362	0.061	0.747	-0.997	-0.400	-0.887	0.839	-0.123
A. sativa straw	Buried	-0.910	-0.787	-0.578	-0.832	0.308	-0.713	0.469	-0.901	0.937	-0.067
Glycine max	Surface	0.627	0.730	-0.046	0.753	0.848	0.038	-0.782	0.777	-0.720	0.536
Glycine max	Buried	0.117	0.105	0.020	0.072	0.588	-0.486	0.189	-0.010	-0.058	-0.188
					N						
L. cuneata	Surface	0.428	0.532	-0.647	-0.184	0.727	-0.165	-0.228	-0.796	0.800	-0.994
L. cuneata	Buried	-0.862	-0.678	0.018	-0.521	-0.588	-0.682	-0.067	-0.527	0.595	0.041
A. julibrissin	Surface	0.541	0.455	-0.386	0.582	0.335	-0.905	-0.928	0.601	-0.553	0.975
A. julibrissin	Buried	0.708	0.926	-0.592	0.590	0.878	0.349	0.824	0.930	-0.990	0.342
A. sativa straw	Surface	-0.616	-0.683	0.756	-0.520	-0.971	0.848	-0.074	1.000	-0.996	-0.355
A. sativa straw	Buried	-0.764	-0.062	-0.954	-0.352	0.354	-0.099	-0.344	-0.430	0.386	-0.634
Glycine max	Surface	-0.247	-0.079	-0.868	-0.043	-0.018	-0.467	-0.147	0.697	-0.593	0.865
Glycine max	Buried	-0.048	-0.211	0.341	-0.270	0.404	-0.462	0.255	-0.352	0.312	0.011
					Mass						
L. cuneata	Surface	0.767	0.869	-0.936	0.710	0.477	-0.512	-0.536	-0.060	0.060	-0.438
L. cuneata	Buried	0.071	-0.203	0.732	-0.091	-0.203	-0.177	0.838	0.999	-0.993	0.396
A. julibrissin	Surface	-0.191	-0.288	0.360	-0.143	-0.410	-0.948	-0.928	-0.119	0.177	0.856
A. julibrissin	Buried	0.629	0.046	0.465	-0.124	0.318	-0.863	0.461	0.154	-0.040	0.715
A. sativa straw	Surface	0.149	0.236	-0.336	0.033	0.728	-0.999	-0.426	-0.873	0.823	-0.151
A. sativa straw	Buried	-0.901	-0.914	-0.466	-0.682	-0.025	-0.615	0.688	-0.995	0.993	0.282
Glycine max	Surface	0.597	0.704	-0.079	0.728	0.827	0.000	-0.759	0.773	-0.710	0.567
Glycine max	Buried	0.201	0.360	-0.342	0.367	0.626	-0.491	0.158	0.298	-0.393	-0.415

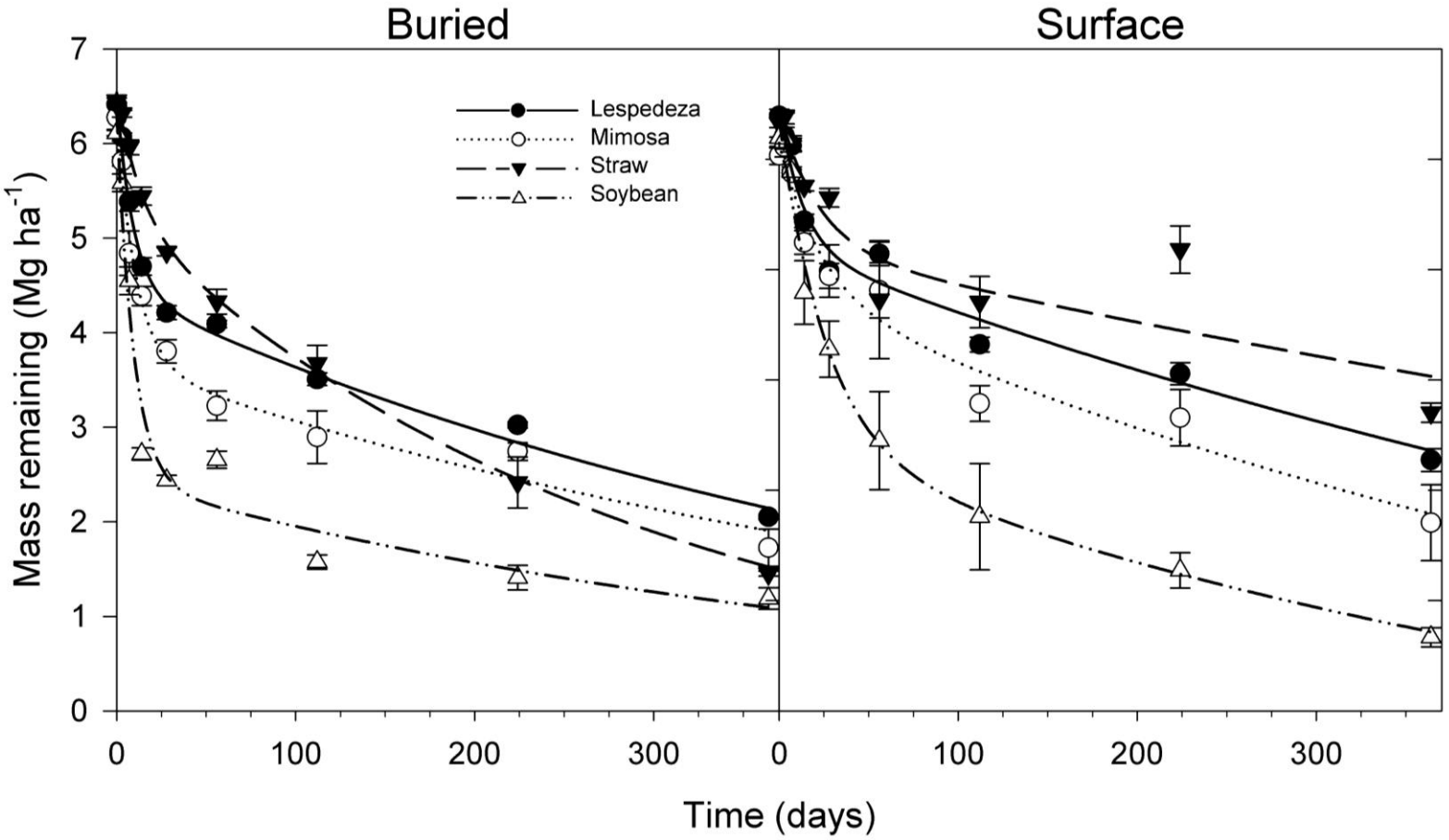

Figure 1. Mass loss from surface and buried residue on an area basis. Residues were placed at an equivalent rate of 6.7 Mg ha^{-1} on an air dried basis, but results are reported on an oven dry basis. Error bars represent standard errors of the mean.

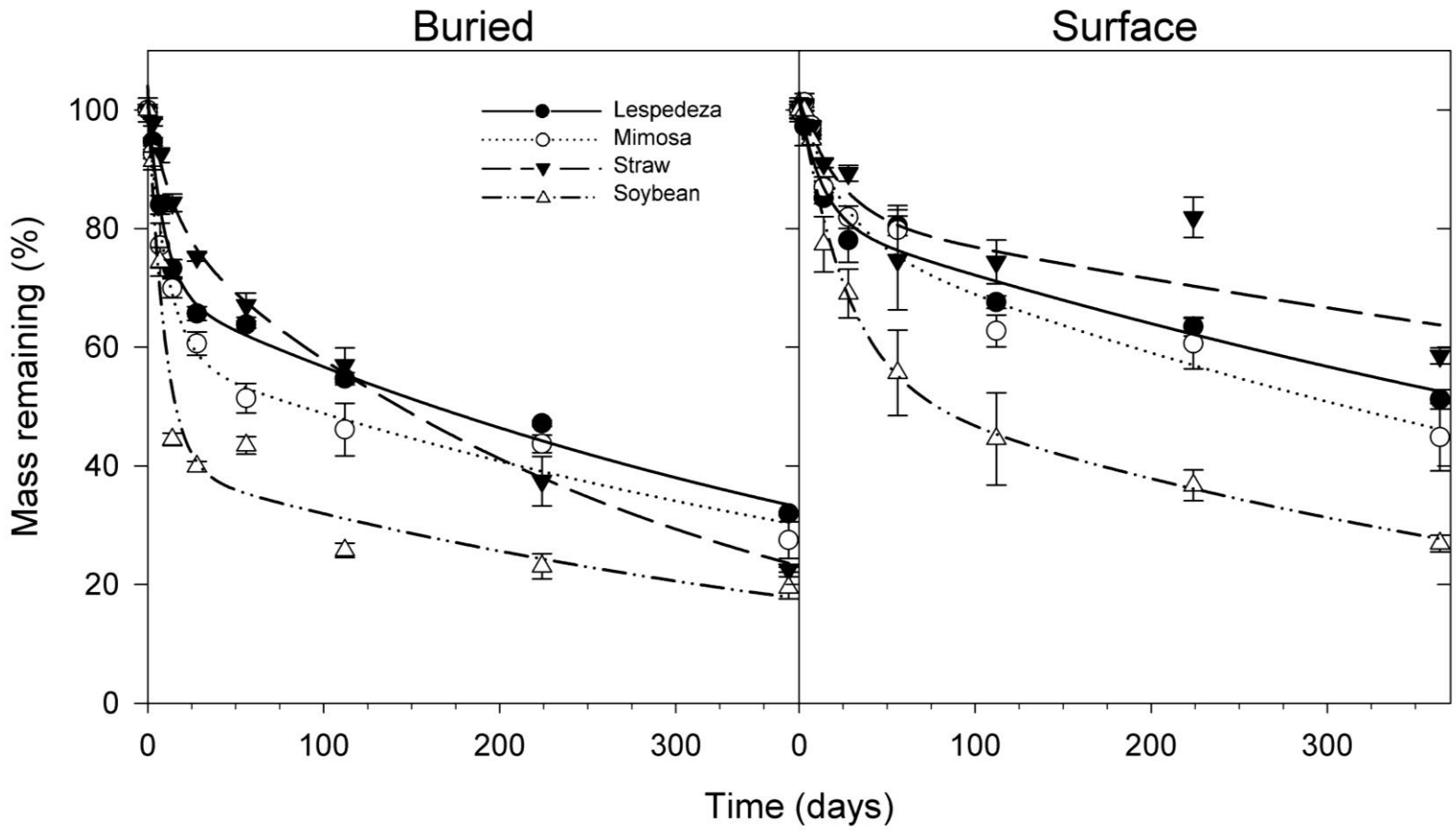

Figure 2. Mass loss from surface and buried residue on a percent basis. Error bars represent standard errors of the mean.

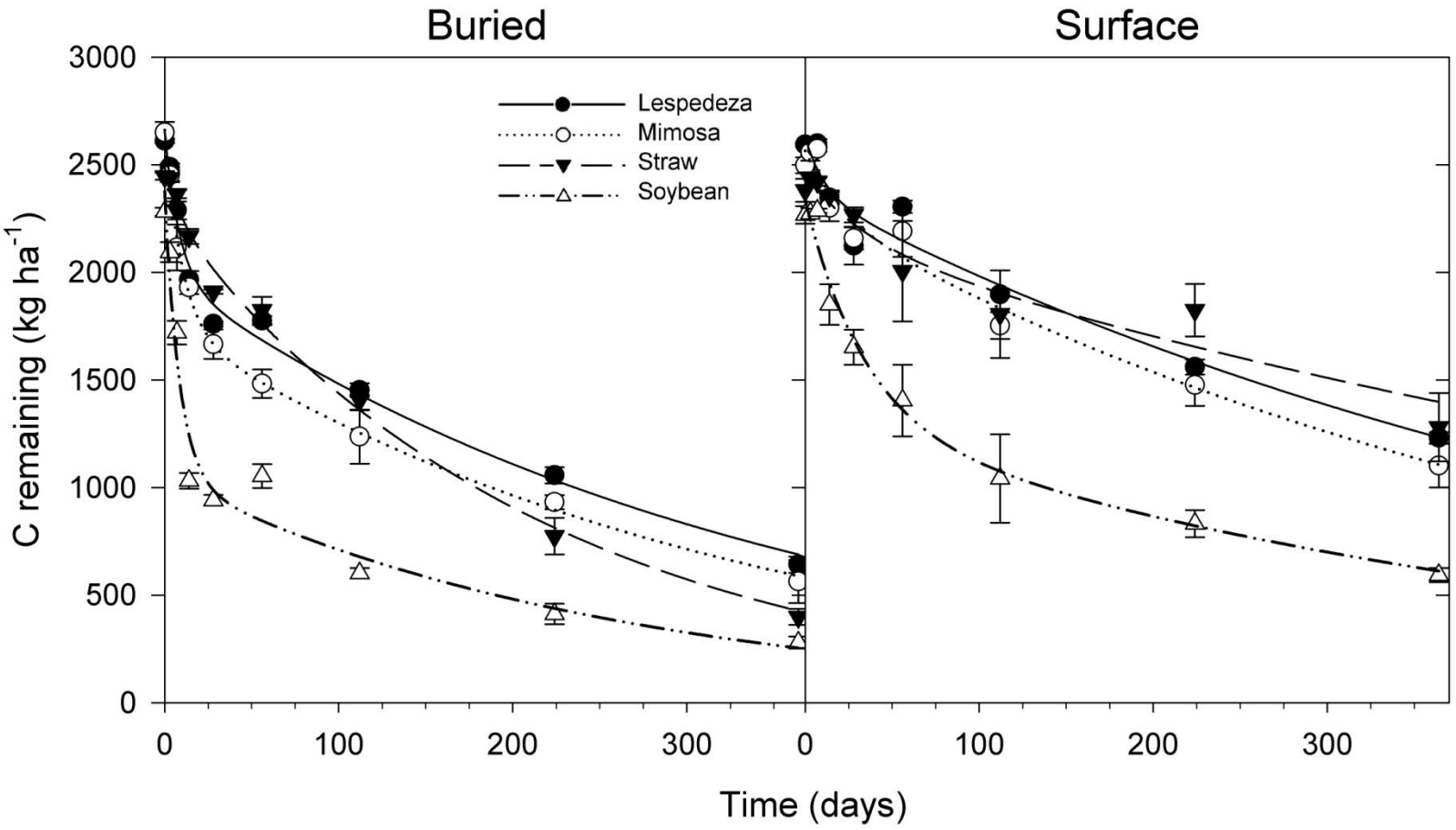

Figure 3. Carbon loss from surface and buried residue on an area basis. Error bars represent standard errors of the mean.

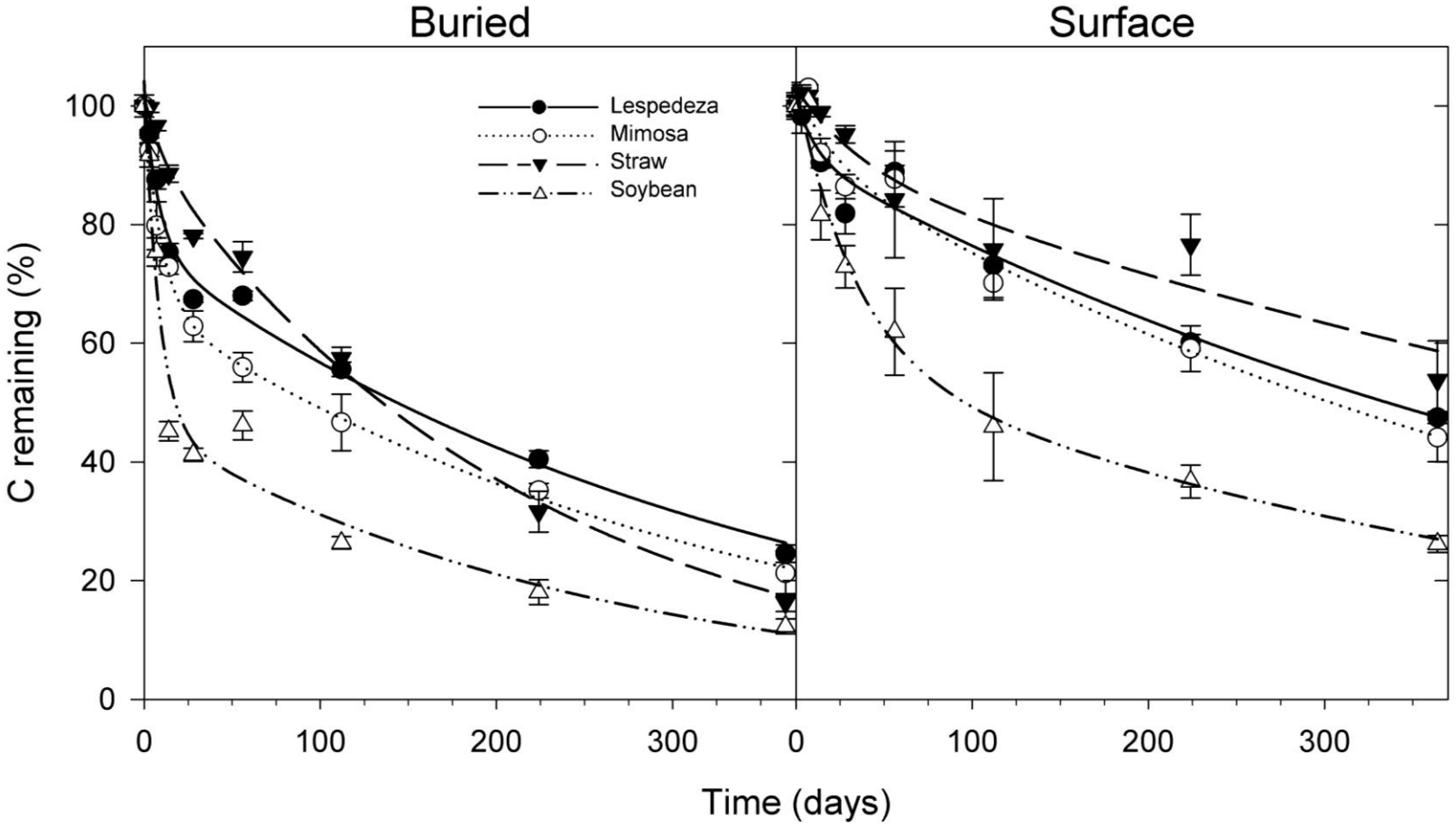

Figure 4. Carbon loss from surface and buried residue on a percent basis. Error bars represent standard errors of the mean.

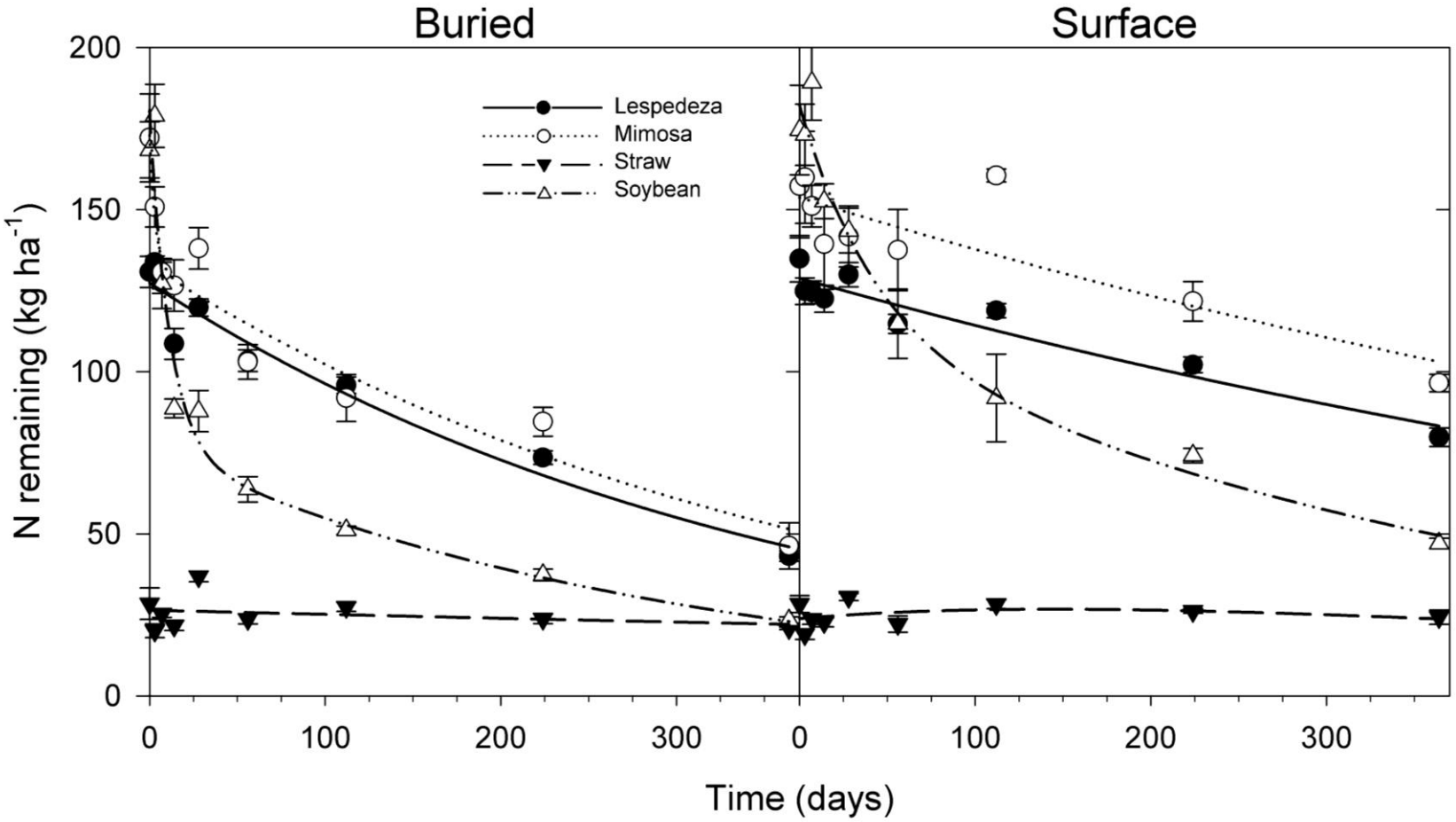

Figure 5. Nitrogen loss from surface and buried residue on an area basis. Error bars represent standard errors of the mean.

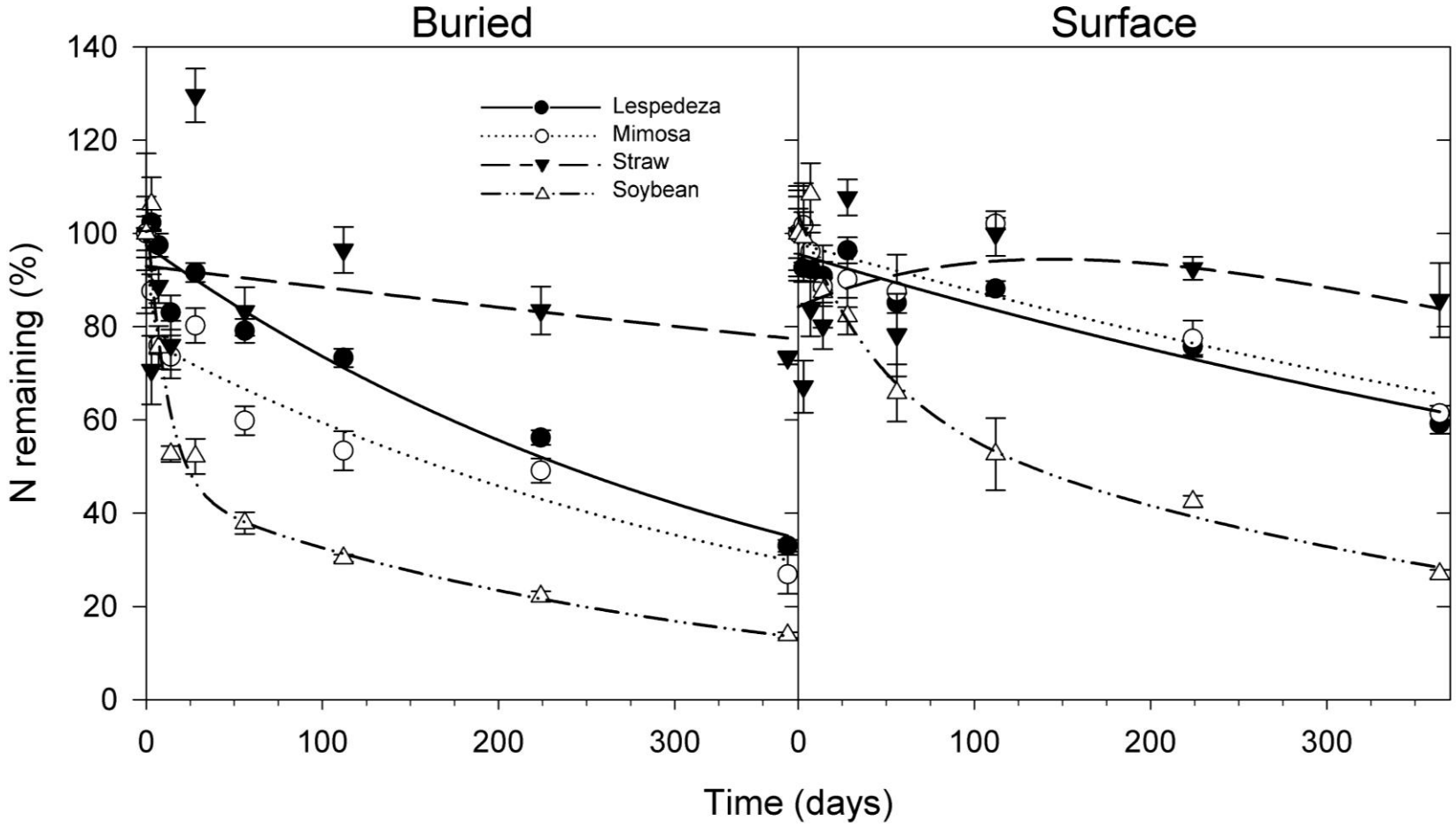

Figure 6. Nitrogen loss from surface and buried residue on a percent basis. Error bars represent standard errors of the mean.

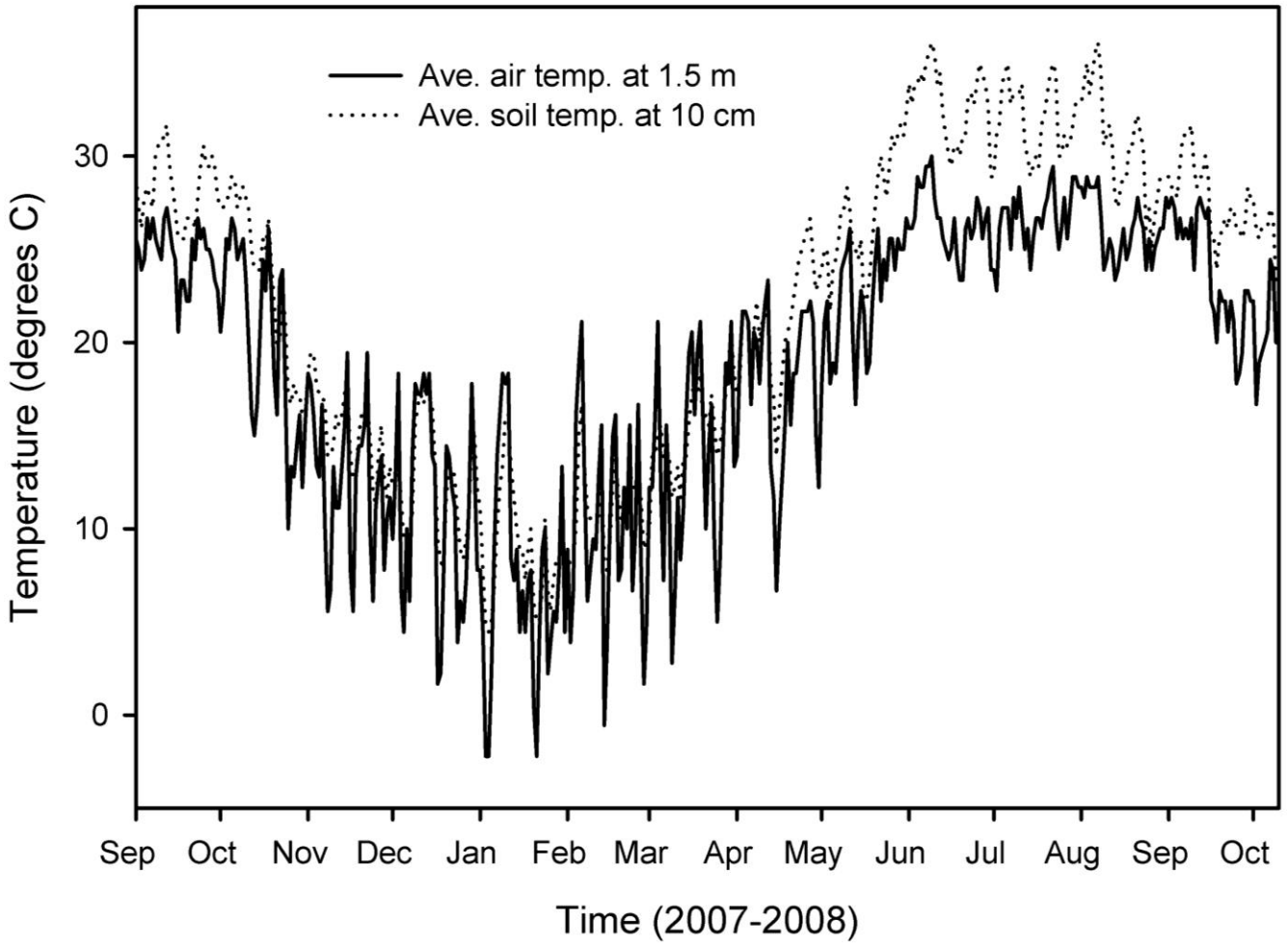

Figure 7. Average air temperature at 1.5 m and soil temperature at 10 cm depth near the study site.

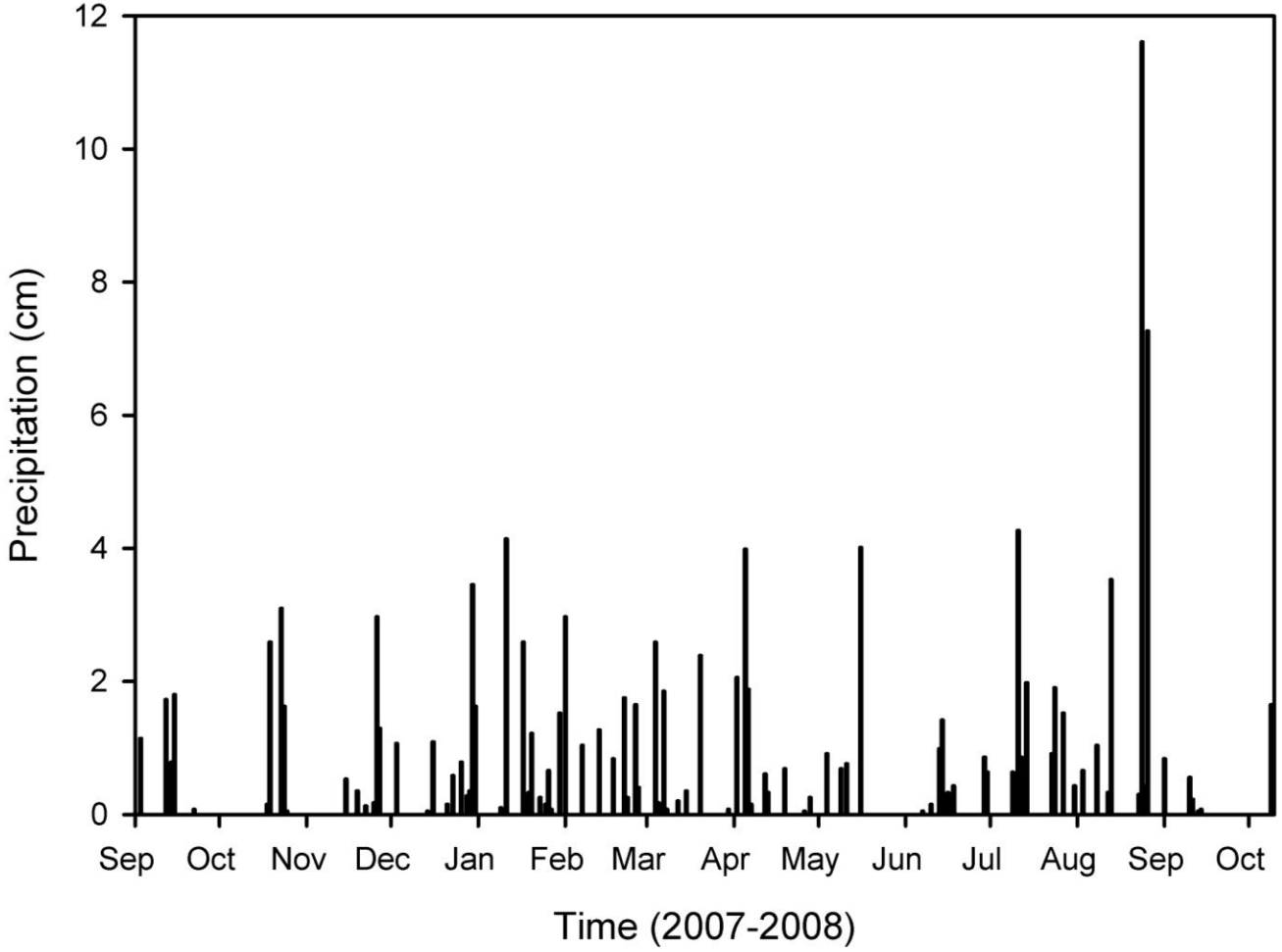

Figure 8. Daily precipitation near the study site.

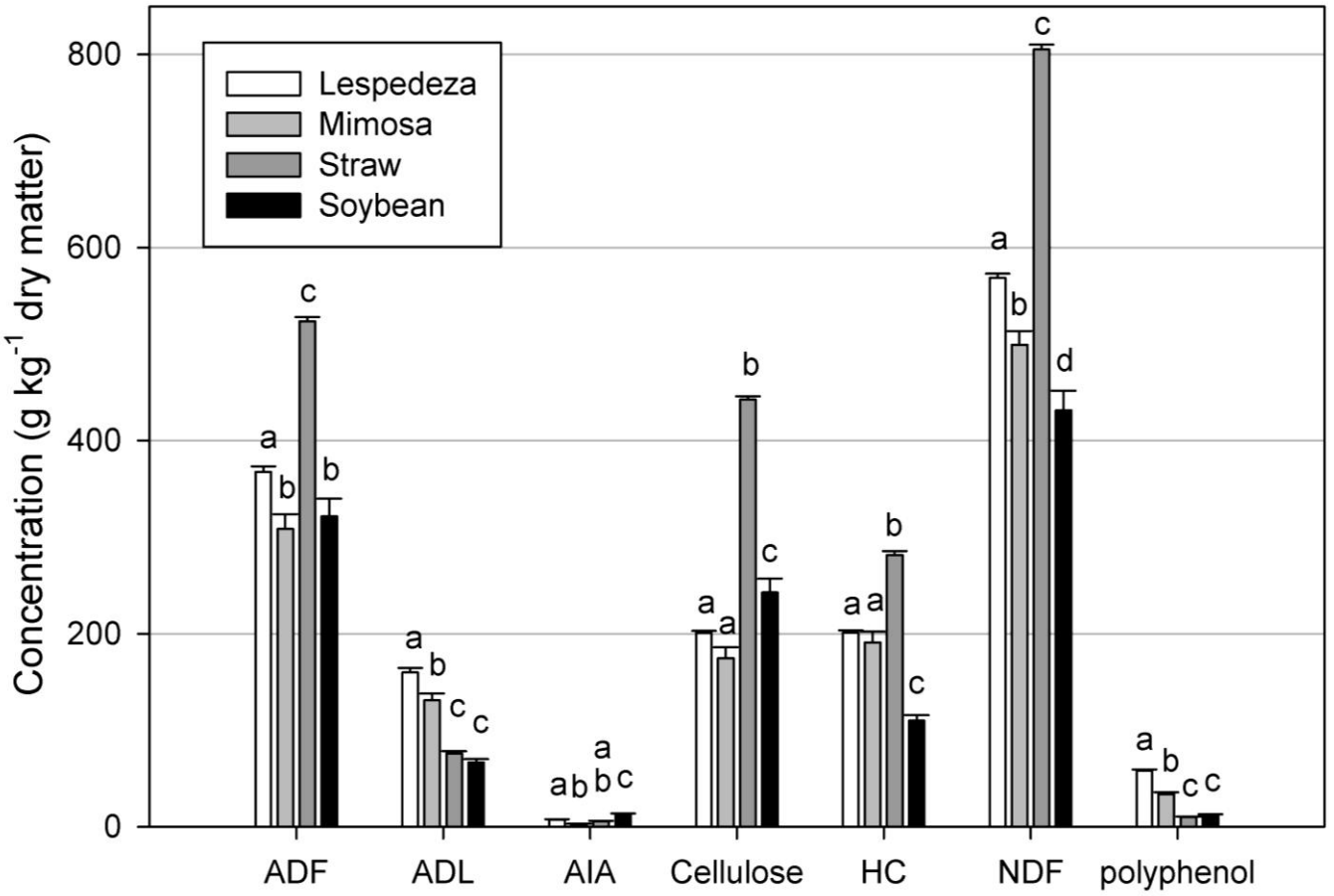

Figure 9. Initial fiber content of residues. ADF = acid detergent fiber; ADL = acid detergent lignin; AIA = acid insoluble ash; HC = hemicellulose; NDF = neutral detergent fiber. Error bars represent standard errors of the means. Means followed by the same letter are not significantly different at $p<0.05$.

III. Effect of High Biomass Cover Crops and Organic Mulches on Soil Carbon and Nitrogen Three Years after Conversion to No-Till in a Collards Agroecosystem

Abstract

Organic producers interested in the adoption of conservation tillage continue to face considerable challenges, particularly with regard to weed control. Previous work has demonstrated that high biomass cover crops in conjunction with organic mulches can provide adequate weed control in a no-till system, but the effects of high biomass cover crops and mulches on soil quality during no-till vegetable production has not been investigated. The objective of this study was to determine the effects of organic mulches and forage soybean (*Glycine max* (L.) Merr., cv. 'Derry', Group VI) as a summer cover crop on soil organic carbon (SOC), C mineralization, total soil nitrogen (N), aggregate stability, and yield in a no-till system without the use of herbicides during limited-input fall collard (*Brassica oleracea* L. var. Champion) production in central eastern Alabama. All treatments, including controls, increased SOC in the 0-5 cm soil depth, indicating that high biomass no-till was more influential on SOC accumulation than the inclusion of summer cover crops or organic mulches. Treatments did not affect collard yield, which averaged 17,900 kg ha^{-1} yr^{-1} harvested as whole heads. Mulches applied at 6.7 Mg ha^{-1} yr^{-1} did not mineralize nutrients in sufficient quantities to meet collard demands after three years, although the crop appeared healthy. This research highlights the need for careful nutrient management under limited-input no-till vegetable production.

Introduction

Organic agriculture is one of the fastest growing sectors in the US agricultural industry. The sale of organic foods in the US had an average annual growth rate of 19.5% from 1998-2003, representing $10.38 billion in consumer sales in 2003 (OTA, 2004). The number of certified organic farms in the US increased 103% between 1997 and 2005, while total acreage increase 201% (USDA, 2009a). Although organic producers make efforts to adopt sustainable approaches on their farms, they often use conventional tillage because they cannot use herbicides to kill weeds and cover crops. Conventional tillage destroys organic matter, increases erosion risk, damages soil structure, reduces aggregate stability, promotes crusting and decreases soil moisture compared to no-till (Bessam and Mrabet, 2003; Raczkowski et al., 2002). Research conducted by Dr. Ron Morse has demonstrated the feasibility of no-till organic vegetable production in Virginia (Rodale, 2005).

The key to organic no-till is the production of high biomass cover crops. High biomass cover crops are desirable because they contribute substantial amounts of soil organic matter (SOM) and cover a large percentage of the soil surface. However, high biomass cover crops with low C:N ratios such as sunn hemp (*Crotalaria juncea* L.) or forage soybean require additional weed control as residues decompose (Ron Morse, personal communication, May 17, 2005), necessitating some form of weed control later in the season. On the organic farm, further weed control is often accomplished by hoeing, cultivating or purchasing off-farm inputs, which can be costly in terms of labor, transportation and input costs. Alternatively, mulching materials can be provided *in situ*

via production of high biomass perennial legumes grown as hedgerows in the field border or within the field itself, such as in alley cropping systems (Jordan, 2004). High biomass perennial legumes are desirable because they can provide quality mulch, rich in N as well as other nutrients that become available to the crop as it decomposes, reducing the need to supply nutrients from other sources. Nutrients not used by the concurrent crop become potentially available to subsequent crops upon mineralization. Perennial legumes do not require re-seeding and often are more productive than annual species. By growing leguminous mulches *in situ*, the costs of purchasing and transporting mulch are eliminated and the cost of providing nutrients to the crop is also reduced.

The rate at which plant residues and mulches decompose is dependent upon several factors. Mulches with a lower C:N ratio tend to decompose faster than those with a low N concentration, while presence of lignin and polyphenols slows decomposition rates (Fox et al., 1990). A balance must therefore be achieved between nutrient release and mulch persistence. Mimosa (*Albizia julibrissin* Durazz.), a leguminous tree, and lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don) may be appropriate perennial leguminous species for mulch production because they can tolerate heavy pruning and have been shown to produce up to 9.0 Mg of dry matter per hectare in Alabama (Kang et al., 2008; Mosjidis, 1996). Although both species have a low C:N ratio, lespedeza is likely to decompose more slowly due to higher tannin concentrations, and thus persist longer as mulch (Kalburtji et al., 1999). Wheat (*Triticum aestivum* L.) straw, a common organic mulch having a high C:N ratio, is likely to have slower nutrient release rates than mimosa prunings or lespedeza cuttings, and therefore may be more effective for weed suppression later in the growing season due to increased persistence.

Summer cover crops have the capacity to improve soil quality, recycle or contribute nutrients, reduce weed growth, minimize soil erosion and produce large amounts of biomass in a short period of time (Creamer and Baldwin, 2000). After termination, nutrients released from residues are available for subsequent crops upon mineralization. Forage soybean is an annual legume that may be a useful in the Southeast for its utility as a high biomass, low C:N summer cover crop.

Timing of cover crop termination is important in organic no-till systems. Crimping and rolling cereal cover crops may not be sufficient to produce an adequate kill if the crop is not mature. At the soft-dough stage of cereal growth, roller-crimping was as effective as herbicide in achieving an adequate kill (Ashford and Reeves, 2003). This period is identified as the 11.1 to 11.2 stage according to the Feekes Growth Stages (Large, 1954). This stage of growth is achieved around April 15-20 for rye (Donald Ball, personal communication May 23, 2005) in central Alabama. Alternatively, adequate termination of cover crops has been achieved by flail-mowing (Morse, 1999).

The objective of this study was to determine the effects of organic mulches and forage soybean as a summer cover crop on SOC, C mineralization, total soil N, aggregate stability, and yield in a no-till system without the use of herbicides during limited-input fall collard production.

Materials and Methods

The study was conducted at the E.V. Smith Research Center Plant Breeding Unit in South Tallassee, AL (N 32º29.29' W85º53.26, 66 m elevation) between 2005 and 2008 on a Wickham fine sandy loam soil, 0-2% slopes (Wickham fine-loamy, mixed,

semiactive, thermic Typic Hapludults). The experiment was a 2 (summer cover crops) by 4 (mulch types) factorial randomized complete block design replicated four times. Each block was 24.4 m long and 9.1 m wide, with experimental units that measured 9.1 m long and 3.0 m wide. Two main treatments consisted of a Derry forage soybean summer cover crop and a no summer cover crop control. Four sub-treatments consisted of in situ organic mulches: mimosa prunings ≤1 cm in diameter, lespedeza (cv. AU Grazer) cuttings, wheat straw, and a no-mulch control.

The plots were disk harrowed at the initiation of the experiment in October 2005, then limed and fertilized according to soil test recommendations. Each year, a winter cover of rye (*Secale cereale* L. cv. Elbon) was mechanically terminated using a roller-crimper (Ashford and Reeves, 2003) or chemically terminated if an adequate kill was not obtained in late April. Two weeks after termination, summer cover crop treatments were planted using inoculated Derry forage soybean at 112 kg ha^{-1} on 19 cm rows using a Marliss no-till drill. In mid to late August, summer cover crops were mechanically terminated using a roller-crimper or chemically terminated if an adequate kill was not obtained. Two weeks after summer cover crop termination, rows were cleared using row cleaners on a Kinze no-till planter and collards seedlings were transplanted 43 cm apart using a single row RJV 600 no-till transplanter (R J Equipment, Ontario Canada) on 76 cm rows. No subsoiling shank was used at any point during the experiment. Mulches were applied at a rate of 6.7 Mg ha^{-1} (oven-dry basis) 21 days after transplanting. Collards were fertilized at a rate of 202 kg N ha^{-1} in three split applications and irrigated using a traveling gun as needed.

Hand harvest operations were conducted 65-69 d after transplanting, followed by drilling a winter cover crop of rye at a rate of 101 kg seed ha^{-1} on 19 cm rows. Yield was determined by hand-harvesting two 2-m rows within the sampling area. The harvested heads were counted for marketable heads and weighed. Biomass samples were collected by harvesting all above-ground biomass within two 0.25 m^2 quadrats collected randomly within the sampling area. Aggregate stability of the 0-5 cm soil depth was determined at the end of the experiment after the final collard harvest (Kemper and Rosenau, 1986).

A laboratory incubation study was conducted to determine potential C mineralization from each plot after three years. Soil was sampled at 0-10 cm depth immediately following the final collard harvest. Samples were immediately cooled to 4 ºC and transported to the laboratory, where gravimetric water concentration was determined by drying a subsample in an oven at 105 ºC. Samples were incubated at 25 ºC for 34 days at 89% of field capacity. (Rain prevented incubation of fresh soil samples at 85% of field capacity.) Field capacity was determined using pressure plates at 0.1 bar (Zekri and Parsons, 1999). Carbon mineralization was determined by trapping CO_2 evolved from 25 g of soil (on a dry weight basis) in 8.0 mL of 1N NaOH traps and back-titrating excess base with 1.0165 N HCl in the presence of $BaCl_2$ (Coleman et al., 1978).

Total SOC and N from each experimental unit at 0-5, 5-10, and 10-20 cm depths were determined by LECO TruSpec CN (Leco Corp, St. Joseph, MI) before the initiation of the experiment on November 15, 2005 and again on November 21, 2008, immediately following the final collard harvest. Collard leaf tissue C, N, P, K, Ca, Mg, Fe, Mn, Cu, and Zn were determined by collecting 12 mature leaves from each plot during the middle of the 2008 growing season (Mills and Jones, 1996) and oven dried at 65 ºC. Leaf tissues

were ground to pass through a 1 mm sieve and analyzed for total N and C by LECO TruSpec CN (Leco Corp, St. Joseph, MI). Tissue analyses of P, K, Ca, Mg, Fe, Mn, Cu, and Zn were determined using inductively coupled argon plasma spectrophotometry (ICAP). Aggregate stability was determined on the 0-5 cm soil depth at the end of the experiment using methodology described by Kemper and Rosenau (1986).

Significant effects were identified by analyses of variance as implemented in SAS 9.1.3 using PROC GLIMMIX procedures and maintaining blocks as a random effect (SAS, 2003). Effects were considered significant at $p < 0.05$. Means and standard errors of significant effects of the reduced models were obtained using PROC MEANS.

Results and Discussion

Soil organic C concentration did not change over the three year course of the experiment owing to summer cover crop treatments ($p=0.5019$) nor mulching treatments ($p=0.1289$), but did change by depth ($p<0.0001$) (Table 24). Summer cover crop treatments did not alter SOC concentration at any depth up to 20 cm after three years (Table 25). Although the depth by mulch interaction was not statistically significant ($p=0.1359$) (Table 24), it is instructional to investigate trends regarding which mulch types improve SOC and the depth to which the increase is affected. All mulching treatments, including the no-mulch control, increased SOC concentration in the 0-5 cm soil depth compared to project initiation, while only mimosa increased SOC in the 5-10 cm depth and lespedeza increased SOC in the 10-20 cm depth (Table 26). Changes in SOC concentrations after conversion to no-till from alternating crop-fallow systems have been observed elsewhere (Wood et al., 1991). The results imply that conversion to no-till

with the utilization high biomass winter cover crops had a greater impact on the increase in SOC than did the inclusion of organic mulches at a rate of 6.7 Mg ha^{-1} yr^{-1} and forage soybean as a summer cover crop. Similarly, Wood and Edwards (1992) found that conservation tillage had a greater effect on SOC concentrations than did crop rotations.

In contrast to comparing treatment effects to initial conditions, we might look at the final results after three years of high biomass no-till. In such a scenario, the summer cover crop treatments did not affect SOC at any depth (Table 27). Table 28 shows pairwise depth comparisons holding mulch constant and pairwise mulch comparisons holding depth constant after three years of high-biomass no-till. For every mulch, the SOC was significantly higher in the 0-5 cm depth compared to the 5-10 and 10-20 cm depth ($p<0.0001$) (Table 28) (Figure 10). However, SOC in the no-mulch control did not significantly differ between the 0-5 and 5-10 cm depths ($p=0.0662$), though the 0-5 cm depth was significantly different from the 10-20 cm depth ($p=0.0009$). This implies that the control did not have as great an increase in SOC as did plots that received mulching treatments, the evidence for which is clearly seen in Figure 10. At the 0-5 cm depth, both mimosa and lespedeza had significantly higher SOC compared to the control (Table 28). Interestingly, the control plots did not significantly differ in SOC from plots that received straw mulches at the end three years of high-biomass no-till ($p=0.1806$). This may due to the longer persistence of straw compared to mimosa and lespedeza mulches, which did not allow for sufficient decay into sapric organic matter that can be sampled using the soil probes employed in this study. None of the mulch comparisons had significantly different SOC at the 5-10 cm nor 10-20 cm depths (Table 28) (Figure 10).

Initial N concentration at the beginning of the experiment did not differ significantly with cover crop treatment at any depth (0-5 cm, $p=0.0933$; 5-10 cm, $p=0.1997$; 10-20 cm, $p=0.8839$), but initial N concentration was significantly different owing to depth ($p<0.0001$, data not shown). These results are expected since N is naturally stratified in the soil profile. This demonstrates the horizontal homogeneity of the N pool at the beginning of the experiment.

Compared to initial total soil N (TSN), the final TSN did not significantly differ due to summer cover crop treatments ($p=0.3992$) nor mulch treatments ($p=0.1057$) (Table 29). Differences were significant, however, by depth ($p<0.0001$), indicating that TSN increase by depth was due to inorganic N fertilization during high-biomass no-till rather than on treatment effects. At every depth and mulch, the final TSN was greater than control N, with the notable exception of wheat straw at 5-10 cm depth (Table 30). This was likely due to N immobilization of fibric and/or hemic straw residue at that depth. The 0-5 cm depth likely contained more fibric straw residue that could not be sampled, while the 10-20 cm depth contained more sapric straw residue that was already beyond the point of N immobilization.

Similar results were obtained from the standpoint of final effects due to treatment applications. Neither mulching treatments ($p=0.1081$) nor summer cover crop treatments ($p=0.6289$) had an effect on the final TSN after three years of high-biomass no-till (Table 31). This was due to the application of inorganic N during fertilization of collards. Total soil N due to summer cover crop treatments at the end of the experiment was not significantly different at any depth (Table 32). This may be expected due to the relatively fast decomposition rate of forage soybean residue.

Analysis of variance of TSN concentration for mulch type by depth showed that all mulch treatments had significant TSN concentrations after three years of no-till ($p<0.0001$; data not shown). This is not to say that the significant levels of TSN were due to mulching treatments; in fact, they were not ($p=0.1081$, Table 31). Instead, the effect was due to N fertilization applied during the experiment. Pairwise comparisons between placement and mulch type on TSN at the end of the experiment are shown in Table 33.

Incubation of soils at the end of the experiment showed no treatment differences for C mineralization (Table 34). The average C mineralization was 12.1 mg C kg^{-1} soil day^{-1}, with a standard error of 0.9 mg C kg^{-1} soil day^{-1} and a standard deviation of 5.3 mg C kg^{-1} soil day^{-1}. Aggregate stability of the 0-5 cm depth did not show any treatment differences at the end of the study ($p>0.8954$) (Table 35). Water stable aggregates averaged 90.8% in the 0-5 cm depth three years after conversion to no-till. These results are in agreement with those reported by Rogers et al. (2004), who found that a single year after conversion to no-till resulted in increased aggregate stability. The findings also concur with a study that found that organic mulches did not significantly affect wet aggregate stability, though the study was conducted over a single season (Schonbeck and Evanylo, 1998).

Average collard yield was 17,900 kg ha-1 yr-1 harvested as whole heads. Collard yield was not significantly different due to any of the treatments, including year ($p>0.2587$; data not shown). This is not unexpected since crop yields are generally more responsive to tillage systems and management than to weed density (El Titi, 2003). Abdul-Baki et al. (1999) also found no yield differences during no-till bell pepper

(*Capsicuum annuum* Mill.) production in an experiment utilizing hairy vetch (*Vicia villosa*) mulch, black plastic, and bare soil. In an experiment comparing black plastic, conventional tillage, and conservation tillage on tomato production, Fujii and Araki (2000) reported no significant yield differences on sandy soils, although yields were higher using hairy vetch cover crops under no-till on volcanic ash soils. However, Abdul-Baki and Teasdale (1993) found that tomato yields were higher under no-till with winter annual legume cover crops than under conventional tillage with black plastic, paper or no-mulch. Similar results were reported during snap bean (*Phaseolus vulgaris* L. var. *vulgaris*) production (Abdul-Baki and Teasdale, 1997). The results indicate that conversion to conservation tillage has a greater impact on yield than the application of mulches.

After three consecutive years of collard production, nutrient concentrations in mature, mid-season leaf tissue were at the low end of those reported in the literature, with the notable exception of N (Table 36) (Mills and Jones, 1996), although soil tests halfway through the experiment (on Feb. 2, 2007) indicated high levels of soil P, K, Mg, and Ca and a pH of 6.2. Although forage soybean residue N can provide part of the N required by subsequent crops, N deficiencies can develop in a single year without the application of supplemental N (Abdul-Baki et al., 1997b). Although laboratory analyses evidenced nutrient deficiencies, it is worth noting that the collards appeared otherwise healthy in the field. This suggests that the nutrients contained in mulches were not mineralized and/or present in sufficient quantities to adequately supply collard requirements after three consecutive years. This underscores the importance of crop rotation as well as the need for careful nutrient management, particularly while under monoculture.

The lack of treatment differences due to mulching seems reasonable when one considers the relatively small amount of biomass due to mulching in comparison to that which accumulated on the plots over the course of three years of high-biomass no-till, averaging 8.3 Mg ha^{-1} yr^{-1} from winter rye and 4.6 Mg ha^{-1} yr^{-1} from summer cover crops. Over three years, mulched plots accumulated approximately 58.8 Mg biomass ha^{-1} while unmulched plots received approximately 38.7 Mg biomass ha^{-1}. The addition of 39 Mg biomass ha^{-1} over three years had a greater effect on SOC and TSN than did an additional 20 Mg biomass ha^{-1} by the application of mulches. Although differences in SOC may exist among mulching treatments in reality, the limited number of replications and the relatively short timeframe of the study likely did not allow for sufficient resolution among treatments. For example, had the experiment been conducted for 10 years, the mulched plots would have accumulated a total of 196 Mg biomass ha^{-1}, while the unmulched plots would have received 129 Mg biomass ha^{-1}, not including any potential weed biomass that may have accumulated over that time. Over such a timeframe, the differences may have been enough to resolve treatment differences among mulches.

Conclusions

Conversion to conservation tillage with high-biomass cover crops resulted in increased SOC within three years. However, the inclusion of forage soybean as a summer cover crop in such a system had negligible effects on SOC, though it may have other effects such as on soil moisture and weed populations. Forage soybean residue did not significantly contribute to SOC accumulation due to a relatively fast decomposition

rate, particularly when large amounts of additional, persistent biomass are included in the system, such as from a rye winter cover crop and/or the inclusion of organic mulches. The application of substantial inorganic N during fertilization can overwhelm any additions to the soil N pool contributed by forage soybean as a summer cover crop.

Mulch nutrient concentrations and/or mineralization rates were insufficient to adequately supply collard requirements, although the crop appeared normal by observation. Although the utilization of high biomass cover crops and organic mulches improved SOC, crop rotation and soil nutrient management should be implemented to maintain or potentially improve soil fertility.

Future studies should consider the total amount of biomass applied to a system in relation to the amount of biomass applied as mulching material when investigating soil chemical and physical properties, such as SOC, TSN, C mineralization and aggregate stability.

Table 24. Analysis of variance for fixed effects of changes in soil organic carbon (SOC) from initiation of no-till to three years after initiation of no-till. The null hypothesis is there were no changes in SOC after three years of no-till compared to project initiation, i.e., H_0: $SOC_{final} - SOC_{initial} = 0$.

Effect	P>F
Depth	<0.0001
Cover	0.5019
Depth x Cover	0.4485
Mulch	0.1289
Depth x Mulch	0.1359
Cover x Mulch	0.8832
Depth x Cover x Mulch	0.2571

Table 25. Analysis of variance comparing cover crop treatment effects on soil organic carbon (SOC) changes over three years of no-till, by depth. The changes in SOC concentration over the course of the experiment was not significantly affected by summer cover crop treatment at any depth.

Depth (cm)	Cover crop comparison		P>F
0-5	Control	*Glycine max*	0.9692
5-10	Control	*Glycine max*	0.8079
10-20	Control	*Glycine max*	0.1848

Table 26. Analysis of variance for mulch type by depth for soil organic carbon (SOC) changes after three years of no-till. The null hypothesis is there were no changes in SOC after three years of no-till compared to project initiation, i.e., H_0: $SOC_{final} - SOC_{initial} = 0$.

Depth (cm)	Mulch	P>F
0-5	Control	0.0107
0-5	*Albizia julibrissin*	<0.0001
0-5	*Lespedeza cuneata*	<0.0001
0-5	*Avena sativa* straw	0.0001
5-10	Control	0.1202
5-10	*Albizia julibrissin*	0.0374
5-10	*Lespedeza cuneata*	0.1792
5-10	*Avena sativa* straw	0.8103
10-20	Control	0.5782
10-20	*Albizia julibrissin*	0.0930
10-20	*Lespedeza cuneata*	0.0168
10-20	*Avena sativa* straw	0.2539

Table 27. Analysis of variance comparing cover crop treatment effects on SOC concentration after three years of no-till, by depth. Cover treatments did not have significantly different SOC concentrations at any depth by the end of the experiment.

Depth (cm)	Cover crop comparison		P>F
0-5	Control	*Glycine max*	0.9212
5-10	Control	*Glycine max*	0.8408
10-20	Control	*Glycine max*	0.1705

Table 28. Analysis of variance for soil organic carbon (SOC) concentration after three years of no-till. Mulches are compared by depth and vice-versa. The null hypothesis is there were no differences among comparisons affecting SOC concentration after three years of no-till, i.e., H_0: $SOC_{final,comparison1} - SOC_{final,comparison2} = 0$.

Mulch	Depth (cm) comparison		P>F
Control	0-5	5-10	0.0662
Control	0-5	10-20	0.0009
Control	5-10	10-20	0.1056
Albizia julibrissin	0-5	5-10	<0.0001
Albizia julibrissin	0-5	10-20	<0.0001
Albizia julibrissin	5-10	10-20	0.2929
Lespedeza cuneata	0-5	5-10	<0.0001
Lespedeza cuneata	0-5	10-20	<0.0001
Lespedeza cuneata	5-10	10-20	0.5662
Avena sativa straw	0-5	5-10	<0.0001
Avena sativa straw	0-5	10-20	<0.0001
Avena sativa straw	5-10	10-20	0.8748

Depth (cm)	Mulch comparison		P>F
0-5	Control	*Albizia julibrissin*	0.0032
0-5	Control	*Lespedeza cuneata*	0.0049
0-5	Control	*Avena sativa* straw	0.1806
0-5	*Albizia julibrissin*	*Lespedeza cuneata*	0.8030
0-5	*Albizia julibrissin*	*Avena sativa* straw	0.0801
0-5	*Lespedeza cuneata*	*Avena sativa* straw	0.1184
5-10	Control	*Albizia julibrissin*	0.5988
5-10	Control	*Lespedeza cuneata*	0.8093
5-10	Control	*Avena sativa* straw	0.3365
5-10	*Albizia julibrissin*	*Lespedeza cuneata*	0.4438
5-10	*Albizia julibrissin*	*Avena sativa* straw	0.1401
5-10	*Lespedeza cuneata*	*Avena sativa* straw	0.4700
10-20	Control	*Albizia julibrissin*	0.3196
10-20	Control	*Lespedeza cuneata*	0.1237
10-20	Control	*Avena sativa* straw	0.6204
10-20	*Albizia julibrissin*	*Lespedeza cuneata*	0.5770
10-20	*Albizia julibrissin*	*Avena sativa* straw	0.6142
10-20	*Lespedeza cuneata*	*Avena sativa* straw	0.2905

Table 29. Analysis of variance for fixed effects of changes in total soil nitrogen (TSN) from initiation of no-till to three years after initiation of no-till. The null hypothesis is there were no changes in TSN after three years of no-till compared to project initiation, i.e., H_0: $TSN_{final} - TSN_{initial} = 0$.

Effect	P>F
Depth	<0.0001
Cover	0.3992
Depth x Cover	0.6579
Mulch	0.1057
Depth x Mulch	0.6281
Cover x Mulch	0.9622
Depth x Cover x Mulch	0.1899

Table 30. Analysis of variance for mulch type by depth for total soil nitrogen (TSN) changes after three years of no-till. The null hypothesis is there were no changes in SOC after three years of no-till compared to project initiation, i.e., H_0: $TSN_{final} - TSN_{initial} = 0$.

Depth (cm)	Mulch	P>F
0-5	Control	0.0003
0-5	*Albizia julibrissin*	<0.0001
0-5	*Lespedeza cuneata*	<0.0001
0-5	*Avena sativa* straw	<0.0001
5-10	Control	0.0251
5-10	*Albizia julibrissin*	0.0014
5-10	*Lespedeza cuneata*	0.0207
5-10	*Avena sativa* straw	0.1191
10-20	Control	0.0238
10-20	*Albizia julibrissin*	0.0002
10-20	*Lespedeza cuneata*	0.0002
10-20	*Avena sativa* straw	0.0051

Table 31. Analysis of variance for fixed effects of total soil nitrogen (TSN) concentration after three years of no-till. The null hypothesis is there were no treatment differences in TSN after three years of high-biomass no-till, i.e., H_0: $TSN_{final} = 0$.

Effect	P>F
Depth	<0.0001
Cover	0.6289
Depth x Cover	0.3731
Mulch	0.1081
Depth x Mulch	0.3771
Cover x Mulch	0.9216
Depth x Cover x Mulch	0.2255

Table 32. Analysis of variance comparing cover crop treatment effects on total soil nitrogen (TSN) concentration after three years of no-till, by depth. Cover treatments did not have significantly different TSN concentrations at any depth by the end of the experiment.

Depth (cm)	Cover crop comparison		P>F
0-5	Control	*Glycine max*	0.9293
5-10	Control	*Glycine max*	0.9958
10-20	Control	*Glycine max*	0.2133

Table 33. Analysis of variance for total soil nitrogen (TSN) concentration after three years of no-till. Mulches are compared by depth and vice-versa. The null hypothesis is there were no differences among comparisons affecting TSN concentration after three years of no-till, i.e., H_0: $TSN_{final,comparison1} - TSN_{final,comparison2} = 0$.

Mulch	Depth (cm) comparison		P>F
Control	0-5	5-10	0.0056
Control	0-5	10-20	0.0001
Control	5-10	10-20	0.1855
Albizia julibrissin	0-5	5-10	<0.0001
Albizia julibrissin	0-5	10-20	<0.0001
Albizia julibrissin	5-10	10-20	0.2865
Lespedeza cuneata	0-5	5-10	<0.0001
Lespedeza cuneata	0-5	10-20	<0.0001
Lespedeza cuneata	5-10	10-20	0.9007
Avena sativa straw	0-5	5-10	<0.0001
Avena sativa straw	0-5	10-20	<0.0001
Avena sativa straw	5-10	10-20	0.5104

Depth (cm)	Mulch comparison		P>F
0-5	Control	*Albizia julibrissin*	0.0033
0-5	Control	*Lespedeza cuneata*	0.0338
0-5	Control	*Avena sativa* straw	0.3353
0-5	*Albizia julibrissin*	*Lespedeza cuneata*	0.3354
0-5	*Albizia julibrissin*	*Avena sativa* straw	0.0367
0-5	*Lespedeza cuneata*	*Avena sativa* straw	0.2311
5-10	Control	*Albizia julibrissin*	0.3375
5-10	Control	*Lespedeza cuneata*	0.8884
5-10	Control	*Avena sativa* straw	0.6090
5-10	*Albizia julibrissin*	*Lespedeza cuneata*	0.4119
5-10	*Albizia julibrissin*	*Avena sativa* straw	0.1445
5-10	*Lespedeza cuneata*	*Avena sativa* straw	0.5150
10-20	Control	*Albizia julibrissin*	0.2485
10-20	Control	*Lespedeza cuneata*	0.2197
10-20	Control	*Avena sativa* straw	0.9967
10-20	*Albizia julibrissin*	*Lespedeza cuneata*	0.9401
10-20	*Albizia julibrissin*	*Avena sativa* straw	0.2469
10-20	*Lespedeza cuneata*	*Avena sativa* straw	0.2182

Table 34. Analysis of variance for fixed effects on carbon mineralization after three years of high biomass no-till with summer cover crops and organic mulches.

Effect	P>F
Cover crop	0.9982
Mulch	0.3228
Cover crop x Mulch	0.7588

Table 35. Analysis of variance for fixed effects on aggregate stability of the 0-5 cm soil depth after three years of high biomass no-till with summer cover crops and organic mulches.

Effect	P>F
Cover	0.9259
Mulch	0.9904
Cover x Mulch	0.8954

Table 36. Nutrient concentrations of mature, mid-season collard leaves during the third consecutive year of collard production.

Nutrient	3rd yr collards		Literature values†	
	Low	**High**	**Low**	**High**
N (g kg^{-1})	41.5	50.0	40.0	50.0
P (g kg^{-1})	2.0	3.3	3.0	7.0
K (g kg^{-1})	23.5	36.6	30.0	45.0
Ca (g kg^{-1})	17.6	27.1	30.0	40.0
Mg (g kg^{-1})	3.4	5.3	2.5	7.5
Fe (mg kg^{-1})	0	75	50	150
Mn (mg kg^{-1})	0	83	30	250
Cu (mg kg^{-1})	0	8	4	20
Zn (mg kg^{-1})	14	23	20	100

† (Mills and Jones, 1996)

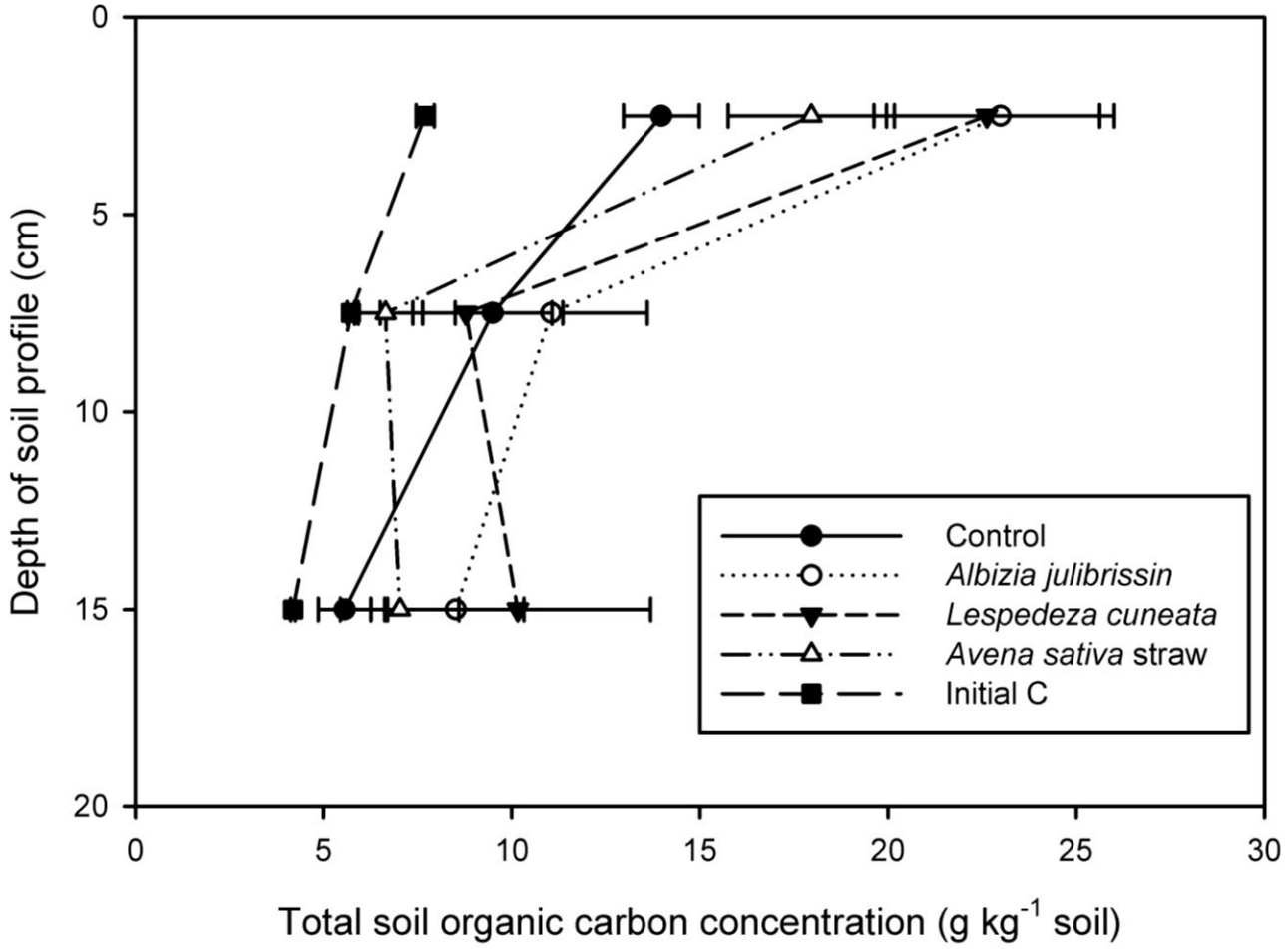

Figure 10. Total soil organic carbon (SOC) concentration at the end of three years of mulching at 6.7 Mg ha^{-1} yr^{-1} compared to a no-mulch control and initial SOC concentration at the study site.

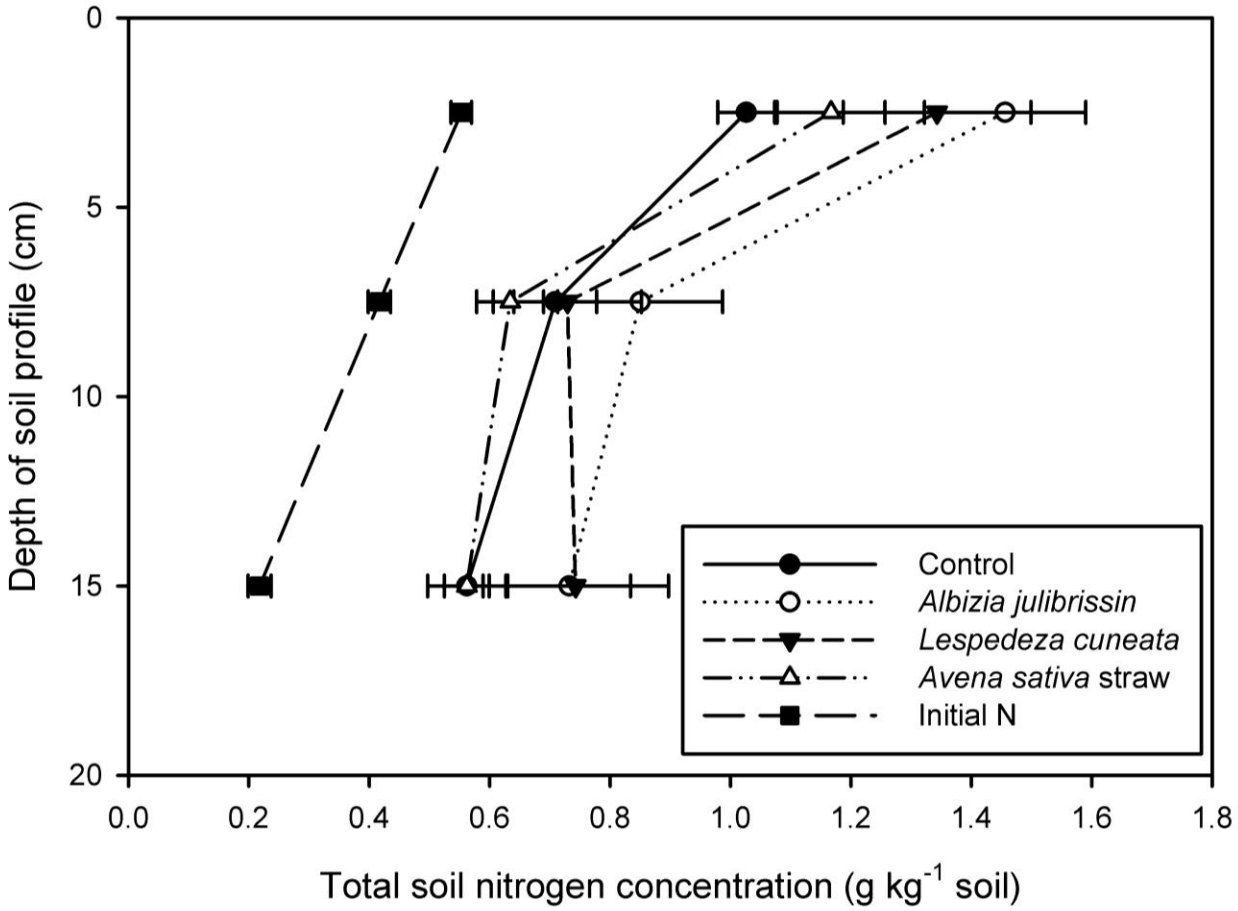

Figure 11. Total soil nitrogen (TSN) concentration at the end of three years of mulching at 6.7 Mg ha^{-1} yr^{-1} compared to a no-mulch control and initial TSN concentration at the study site. The site also received 202 kg N ha^{-1} yr^{-1}.

IV. Peanut Residue Decomposition, Carbon and Nitrogen Release from Three Varieties at Two Locations under Conventional and Conservation Tillage

Abstract

Residue management is an important aspect of crop production systems. Availability of plant residue nitrogen (N) to succeeding crops is dependent on N mineralization rates and therefore on rates of N release during decomposition. Much of the information available on N release rates from peanut (*Arachis hypogaea* L.) residue is based on controlled-environment studies. The objective of this study was to assess N release rates in the field from the residues of three peanut varieties (NC V-11, GA 02-C and ANorden) at two placements (surface and 10 cm deep) and two locations (Upper Coastal Plain Experiment Station in Edgecombe County, North Carolina and Wiregrass Experiment Station in Henry County, Alabama), representing the northern and southern limits of commercial peanut production in the US. Litterbags containing the equivalent of 3.5 Mg ha^{-1} were placed in a completely randomized design, blocked by location, with four replications and retrieved periodically up to 335 days after application. Results showed a statistical difference for placement by time (within location) interactions and fit single or double exponential decay models. Buried residues mineralized N at higher rates than surface residues in North Carolina during the initial 50 days of decomposition. After the initial rapid phase of decomposition, there was no difference in rates of N release at either experiment station. Apart from time, no treatment differences were

found at the Wiregrass Experiment Station. The data show that N is released quickly after peanut harvest if residue is left in the field.

Introduction

Peanut is an important agronomic crop in the southeastern United States. In 2008, 1.31 million acres of peanut were planted with an average of 13.6% residue remaining on the surface after planting (USDA, 2008b). This compares with 1.24 million acres in 1999 averaging 3.9% residue remaining on the surface after planting. Cultivation for weed control decreased from 65% of all planted peanut acreage in the US in 1999 to 34% in 2008 (USDA, 2008b). The trend toward reduced tillage is due to the adoption of conservation tillage among peanut producers.

Availability of plant residue N to succeeding crops is dependent on synchrony of N release and N uptake by succeeding crops and therefore on residue N mineralization rates (Bruulsema and Christie, 1987). An increased understanding of C and N mineralization from surface and buried residue may improve no-till residue management (Quemada and Cabrera, 1995).

Isaac et al. (2004) found that the same species decomposed at different rates depending on location. Site of production can have significant impacts on intraspecific litter quality (Berg and Tamm, 1991; Vitousek et al., 1994), where residue quality can be affected by nutrient use efficiency, water use efficiency (Vitousek et al., 1994), soil nutrient status, and soil pH (Sanger et al., 1996). Therefore, it is important that decomposition studies utilize residue grown on site.

Research on decomposition rates of small grain residues has shown that there is an inverse relationship between decomposition rates and the initial amount of biomass applied (Brown and Dickey, 1970; Steiner et al., 1999; Stott et al., 1990; Stroo et al., 1989). If that conclusion remains true with high N content residues such as peanut, it may be the case that litterbag studies underestimate the decomposition rate of buried residue, since the residue is massed in a single location inside the litterbag under the soil surface instead of relatively evenly distributed throughout the plow layer. Myers et al., (1997) noted that efficiency of synchronicity is reduced when nutrient supplies, in this case peanut residue, are evenly distributed in the soil.

Location comparisons on N release rates from surface and incorporated peanut residue are lacking for the peanut growing region of the US. The objective of this experiment was to assess mass loss and C and N mineralization rates from three peanut varieties at two locations under simulated conservation and conventional tillage systems.

Materials and Methods

A field decomposition study was set up at the Wiregrass Research and Extension Center (WGS) (31º21’05”N, 85º20’10”W, 117 m elevation) on a Dothan fine sandy loam 0-2% slope (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults, pH 6.1) and at the Upper Coastal Plain Experiment Station (NC), Edgecombe County, North Carolina (35º56’07”N, 77º46’31”W, 34 m elevation) on a Norfolk loamy sand, 2-6% slope (Fine-loamy, kaolinitic, thermic Typic Kandiudults, pH 6.4). Three peanut varieties, ANorden (runner type), NC V-11 (Virginia type) and GA 02-C (runner type), were grown at each research site to supply residue. Nylon mesh bags measuring 20 cm by 10 cm with 50 µm

to 60 µm openings were used to determine biomass breakdown and N release patterns of peanut residues in the field. Residue, consisting of mainly leaves and stems with very little root, was collected post-harvest, air dried, and packed into the nylon mesh bags to represent 4.5 Mg ha^{-1} (9 g bag^{-1}). The samples of variety NC V-11 at NC contained increased moisture due to recent rainfall and were therefore placed at a rate of 2.5 Mg ha^{-1} on an oven-dry basis, though efforts were made to air dry the samples as quickly as possible. Sub-samples of the residue were oven dried to account for moisture and determination of total C and N was facilitated by dry combustion with a LECO TruSpec CN (Leco Corp, St. Joseph, MI). Results were reported on an ash-free oven-dry weight basis (Cochran, 1991).

Each peanut variety was placed on the soil surface and buried at 10 cm depth. The treatments were arranged in a completely randomized design with 4 replicates. Twenty-four bags were retrieved from each location during each sampling period. At WGS, litterbags were retrieved 0, 4, 8, 15, 29, 59, 114, 175, 225 and 339 days after application. At NC, litterbags were retrieved 0, 4, 7, 14, 21, 49, 112, 175, 224 and 335 days after application. The contents of each bag were weighed for dry matter determination, dried at 60 ^{o}C for three days, ground to pass a 16 mesh sieve and analyzed for total C and N by dry combustion with a LECO TruSpec CN (Leco Corp, St. Joseph, MI). Sample contamination by soil was accounted for by converting all data to an ash-free dry weight basis by ashing 1.0 g of the samples in muffle furnace at 400 ^{o}C for 12 h and determining the ash free dry weight (Cochran, 1991).

Statistical significance of treatments was determined using Proc Mixed (SAS, 2003) at the 95% confidence level. Assumptions related to this procedure were checked

by inspection of residuals. Least squares estimates for nonlinear models were determined using four parameter double exponential decay models (Systat, 2008).

Results and Discussion

Mass loss

All main effects, including location, variety and placement, were statistically significant during the study, whether the data were expressed on an absolute basis (Mg ha^{-1}) or on a normalized basis (percent mass remaining) (Table 37). With the exception of variety by placement, all interactions were significant as well. It is instructive to examine the significant variety by placement by location interaction. When the main effects are analyzed by location (Table 38), all effects and their interactions were significant at the NC site, regardless of whether the data were presented on an absolute or normalized basis ($p<0.05$). That is, the effect of any one variable differed depending on the level of any other effect.

The interpretation is more complicated at the WGS site. At WGS, variety differences were significant only when the data were presented on an absolute basis (Mg ha^{-1}) ($p=0.028$), but not when the data were normalized ($p=0.80$). The effect of normalized data is to bring data points closer together, and therefore treatment differences tend to be more difficult to discern. This can be seen in Figures 12 and 13, where the variety GA 02-C decomposed slightly faster than the other two varieties when surface placed at WGS, but the decomposition rates were closer together when the data were normalized. This difference is enough to account for the insignificant effect of variety when the data were normalized. Further evidence of the "normalization effect"

on GA 02-C decomposition at WGS is shown in Table 39. While surface placed GA 02-C decomposition at WGS was significantly different from the other two varieties on an absolute basis ($p<0.0083$), it was not on a normalized basis ($p>0.1151$). This illustrates the necessity to exercise caution when interpreting decomposition datasets in the literature. Although a dataset may not appear to have treatment differences when compared on a percent basis, they may in fact be quite different in reality. A normalization effect is also apparent for the variety by placement interaction at WGS (Table 38).

The faster decomposition rate exhibited by GA 02-C can be partially explained by the significantly lower acid detergent fiber (ADF) content of that variety at WGS compared to the other two varieties (Figure 14). Since ADF represents the least easily decomposable fraction of plant material, approximately equal to the cellulose plus lignin content, the significantly lower ADF of GA 02-C may be expected to decay at a faster rate than the other varieties at WGS. However, there was no significant difference between any of the peanut variety decomposition rates when residue was buried at WGS (Table 39, Figure 12). Intimate contact of residue with the soil microbial community not only caused more rapid decomposition compared to surface placed residue ($p<0.0001$, Table 38, Figure 12), but burying the residue had an equalizing effect on the decomposition rate among all residue varieties at WGS, regardless of absolute or normalized data representation ($p>0.1287$, Table 38).

No differences in fiber content among peanut varieties existed at the NC site ($p>0.05$, Figure 15), although there was not enough residue from the variety NC V-11 grown at the NC site to perform a fiber analysis. Differences in the chemical

composition of straw have been previously shown to vary by location, soil quality, and cultivation practices (Chalau et al., 1995). Likewise, ANorden residue was found to be significantly higher in ADF, ash, and neutral detergent fiber (NDF) when grown at WGS than NC, while residue grown at NC was significantly higher in cellulose content (Figure 16, $p<0.05$). By contrast, GA 02-C grown at the two sites was similar in fiber content, except cellulose content, which was higher when grown at NC (Figure 17, $p<0.05$).

Both surface placed and buried NC V-11 residue decomposed at a significantly higher rate than the other two varieties at NC (Table 39, $p\leq0.0005$). A fiber analysis of NC V-11 was not completed due to the lack of sample. The lower amount of initial biomass applied from NC V-11 at NC (Figure 12) makes apparent the advantage of normalized data, allowing the comparison of unequal amounts of residue on a percent of original mass remaining basis (Figure 13). Figure 13 shows that NC V-11 decomposed at a faster rate than the other two residues. However, the inverse relationship between decomposition rates and initial applied biomass for small grain residues has been documented by several studies (Brown and Dickey, 1970; Steiner et al., 1999; Stott et al., 1990; Stroo et al., 1989). If that relationship remains true with high N content residues such as peanut, it may explain why NC V-11 decomposed at a faster rate than the other two varieties at NC (Figure 13).

Table 40 shows there were significant differences between surface placed and buried residue for every variety and at each location ($p\leq0.0338$), with the exception of GA 02-C at WGS when represented on a normalized basis $p=0.1287$). Buried residue is expected to decompose at a faster rate since intimate contact with the soil microbial community allows for faster metabolic activity, retains moisture proximate to the residue,

and since the act of incorporating the residue facilitates a temporarily oxygenated soil atmosphere.

Researchers may be interested to know how location, time, and variety compared while holding tillage type constant. Since NC V-11 was not placed at the same rate as the other two varieties at NC, it is instructive only to make the comparisons on a normalized basis. Table 41 shows that there were significant variety by location differences for both surface placed residue ($p=0.0001$) and buried residue ($p=0.0376$). Further investigation reveals that differences between locations were always significant for each residue type when surface placed ($p<0.0198$, Table 42). When buried, however, only NC V-11 was significantly different between the two locations ($p<0.0001$ on an absolute basis, or $p=0.0211$ on a normalized basis). Again, the lack of fiber analyses for NC V-11 at NC prevents further explanation of this result. It may be surmised that the difference may be due to a faster decomposition of the labile portion of the residue (Figure 13). The general lack of decomposition rates between sites for buried residue is likely caused by the dampening of relatively volatile climatic conditions experienced at 10 cm depth compared to surface conditions. That is, the effect of precipitation and temperature is not as dramatic nor as immediate at 10 cm depth as it is at the surface. Furthermore, temperature amplitude at 10 cm depth is not as great as experienced on the soil surface. It stands to reason, therefore, that buried residue may tend to be more equal at different sites than surface placed residue, all else being equal. Of course, other factors are important as well, including soil pH, soil C and N content, and soil moisture status.

Mass loss data can be adequately described by double exponential decay equations of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B =

the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application. When k_2 is insignificant, the models collapse into single exponential decay equations. Mass loss data fitted to double exponential decay models are shown in Table 43 on a Mg ha^{-1} basis, and in Table 44 on a percent of original mass remaining. In all cases, regression models were significant ($p<0.0267$). The models show that decay rates of recalcitrant portions (k_2) are much lower than those of labile portions (k_1). Furthermore, both decay rate constants were greater when buried than when surface placed. However, k_1 values increased faster than k_2 rate constants when buried, indicating that the majority of the increase in mass loss occurs in the labile portion of the residue when buried. This can be seen in Figures 12 and 13, where mass loss by day 25 was greatly increased when the residue was buried compared to surface placed.

Carbon loss

All main effects, including location, variety and placement, were statistically significant, whether the data were expressed on an absolute basis (Mg C ha^{-1}) or on a normalized basis (percent C remaining) (Table 45). It is worth mentioning that p-values reported in the tables are described on a mass area^{-1} basis instead of a Mg ha^{-1} basis because the values are the same no matter what the units are. For example, the p-values remain the same on a Mg ha^{-1} basis and on a lbs acre^{-1} basis. With the exception of variety by placement, all interactions were also significant. When the main effects variety by placement were analyzed by location (Table 46), all effects and their interactions were significant at the NC site, regardless of whether the data were presented on an absolute or normalized basis ($p<0.05$), except for the highest order interactions.

Generally speaking, the effect of any one variable differed depending on the level of any other.

At WGS, variety differences were significant only when the data were presented on an absolute basis (Mg ha^{-1}) ($p=0.0073$), but not when the data were normalized ($p=0.2422$) (Table 46). In addition, there were no significant differences between surface placed residue and buried residue ($p>0.0599$). However, the days by placement interaction was significant ($p<0.0001$), meaning that the amount of C remaining in the peanut residue was dependent upon both time and placement at WGS. Furthermore, the highest order interaction was significant ($p<0.0230$) so that C remaining was not only dependent on time and placement, but also on variety. This appears anomalous to data represented in Figures 18 and 19, in which the decay rates appear similar between placement treatments at WGS. Further analysis of the data revealed there were statistically significant differences between surface placed and buried residue for NC V-11 at WGS ($p=0.0066$ on an absolute basis; $p=0.0298$ on a normalized basis; Table 47). Interestingly, there were no placement differences between ANorden and GA 02-C at WGS ($p>0.82$; Table 47). The effect can be seen in Figures 18 and 19, where only NC V-11 decomposition rates were different between surface and buried residue at WGS. The lack of placement differences between ANorden and GA 02-C at WGS may be related to the statistically similar lignin content of the two varieties grown at WGS (Figure 14). In NC, placement comparisons were statistically different for every variety. That is, C was released at different rates when comparing buried and surface residue for every variety ($p<0.0105$; Table 47).

At NC, varieties ANorden and GA 02-C released C at the same rate regardless of placement ($p>0.3888$; Table 48), which was likely a result of their similar fiber contents when grown at that site ($p<0.05$; Figure 15). Likewise, NC V-11 released C at statistically faster rates than either of the other two varieties at NC, regardless of placement ($p<0.0002$; Table 48; Figures 18 and 19). At WGS, only GA 02-C and NC V-11 released C at different rates when surface placed ($p<0.0447$), while all other variety comparisons were statistically equal regardless of placement (Table 48). The different release rates exhibited by GA 02-C and NC V-11 at WGS when surface placed were likely due to the different fiber contents (ADF, cellulose, and NDF) and C:N ratio of the initial residue (Figure 14).

Carbon release data were fit to double exponential decay models on an absolute basis and a normalized basis (Tables 51 and 52, respectively). In all cases, the regression models were significant ($p>0.0051$) with reasonably high adjusted R^2 values. As with the mass models, C rate constant values k_1 and k_2 were larger for buried residue than with surface residue. Also, the k_1 values, representing the rate constant for the labile portion of the residue, increased much faster than the k_2 values, which represent the recalcitrant portion of residue C loss. This signifies that the labile C pool of peanut residue was more affected by burying residue than is the recalcitrant C pool.

The similarities between Figures 13 and 19, showing mass loss and C loss, respectively, on a percent basis, were due to the fact that most mass loss is due to C loss as CO_2 from microbial respiration. Although surface placed residue resulted in approximately 0.7 – 1.2 Mg ha^{-1} more mass present after a year compared to buried residue (Figure 12), the difference between surface and buried residue net C remaining

after one year was approximately 0.3 Mg ha^{-1} (Figure 18). Since the difference in C concentration between surface and buried peanut residues was negligible, it does not seem likely that conservation tillage of peanut would improve SOC content over conventionally tilled peanut. Coupled with the low amount of residue produced during peanut production, the high N content of peanut residue and easily decomposable fibers call into question the SOC accumulation usually associated with conservation tillage compared to conventional tillage from peanut residue itself. Typically, conservation tillage utilizes winter cover crops that, when killed, contribute to SOC accumulation, but it remains unknown if peanut residue itself increases SOC under conservation tillage compared to conventional tillage over successive years of cultivation. A three year tillage study utilizing a peanut-cotton (*Gossypium hirsutum* L.) rotation with winter cover crops on a Dothan loamy sand found no significant differences in SOC concentrations between tillage systems at 0-5, 10-15, or 15-20 cm depth, although they did find greater SOC at the 5-10 cm depth using paratill compared to strict no-till (Siri-Prieto et al., 2007). The authors noted that the low amounts of residue returned to the soil after peanut and cotton production can reduce the amount of SOC. Studies conducted on Tifton and Greenville soils showed that both pre- and post-harvest peanut residue C was mineralized at the same rate regardless of soil type (Balkcom et al., 2004). Likewise, the study found no differences in C turnover for pre- and post-harvest residue on either soil. The results of the current study in conjunction with those from previous studies suggest that peanut residue is not produced in sufficient quantities and is mineralized too quickly to significantly contribute to SOC. Field research needs to be conducted to determine if

conservation tillage peanut residue itself accumulates SOC or if the associated cover crops are the main contributors of SOC accumulation under no-till.

Nitrogen release

Since the highest order interaction (days by variety by placement within location) was significant ($p<0.0063$; Table 53) for N release, it is useful to look at the interactions more closely. When analyses were performed within each location, the highest order interaction was not significant at NC ($p>0.8219$; Table 54), while it was significant at WGS ($p<0.0074$). The lack of an interaction at NC is apparent in Figures 20 and 21. At NC, residue placement did not significantly change the order of N release rates. In other words, if the buried and surface graphs for N release at NC were overlaid (Figures 20 and 21), there would not be an overlap, or interaction, between any of the release rates. The opposite was true of the WGS site. At NC, the days by placement interaction was also not significant ($p>0.0652$; Table 54); there were no significant differences between surface placed and buried peanut residue. The lack of treatment differences was likely due to the high standard errors in the data, especially considering that the p-value was so close to the threshold value of 0.05.

It has already been noted that the variety NC V-11 was not placed at the same rate as the other two varieties at NC, so it is useful to examine treatment comparisons on a normalized basis. While variety differences were significant at NC ($p<0.0001$; Table 54), as were placement differences ($p=0.0083$), the variety by placement interactions were not ($p=0.7250$). However, contrasting placement treatments by variety and location showed that there was a significant difference between surface and buried ANorden residue at NC

(p=0.0487; Table 55). GA 02-C released N at the different rates depending on placement (significant at p=0.0509) at NC, but NC V-11 did not (p=0.3209). At WGS, all residues released N at the same rate regardless of placement (p>0.3828).

At NC, NC V-11 released N at faster rates than the other two varieties regardless of placement (p<0.0070; Table 56; Figure 21), while there were no statistical differences in N release rates between ANorden and GA 02-C (p>0.6967). At WGS, all varieties released N at the same rate (p>0.3136; Table 56; Figure 21).

The lack of placement and residue type differences at WGS at first may appear enigmatic, especially considering that there were significant differences in ADF, NDF, and lignin content for GA 02-C grown at WGS (Figure 14). However, relatively cooler temperatures at NC (Figure 22), particularly during the labile phase of decomposition, limited microbial activity at the site. Meanwhile, less frequent and less intense rainfall events at NC (Figure 23) did not allow for rapid leaching of mineralized N.

Table 57 shows that there were no location nor variety differences for N release from buried residue (p=0.6990 and 0.0969, respectively). Surface placed residue, however, did exhibit significant location differences (p=0.0055) as well as significant variety by location interactions (p=0.0037). Holding variety and placement constant, there were N release differences between locations for surface placed ANorden (p=0.0031; Table 58) and GA 02-C (p=0.0028) residue. Both varieties released N at a faster rate at WGS than NC (Figure 21), likely due to the warmer temperatures and greater precipitation at WGS. No location differences were apparent for any buried residue, although the variety NC V-11 did approach the significance threshold for

location differences (p=0.0537; Table 58). It is therefore arguable that buried NC V-11 residue released N at a faster rate at NC than at WGS (Figure 21).

Nitrogen release data were fit to double exponential decay models on a per area basis (Table 59) and on a normalized basis (Table 60). In some cases, the models collapsed into single exponential equations when the recalcitrant portion of the residue did not release significant amounts of N over time (Figures 20 and 21). The recalcitrant portions of buried ANorden and GA 02-C at NC had very similar decay rates ($48.0e^{-0.002X}$ and $47.8e^{-0.002X}$, respectively; Table 59), accounting for the overlapping models beyond day 25 in Figure 20. When the data were modeled on an absolute basis, the significance of regression was generally significant, with the exception of surface placed NC V-11 at NC, which approached the significance threshold (p=0.0541; Table 59), though the adjusted R^2 value for that model was abnormally low (0.544). This was likely due to the small amount and fast release of labile N for that variety, location and placement (Figure 20). The same issue was apparent when the data were represented on a normalized basis (Table 60). However, normalized models also showed an insignificant regression fit for buried ANorden in NC (p=0.0570, adjusted $R^2 = 0.535$) probably due to the outlying datum at day = 114.

At the end of a year, the difference in N content between surface and buried peanut residue was negligible, approximately 0 kg N ha^{-1} yr^{-1} at WGS and 4 kg N ha^{-1} yr^{-1} at NC (Figure 20). Although peanut production under conservation tillage may have other benefits, the data show that N contribution is not significant. Similar conclusions were drawn by Meso, et al. (2007) in a peanut-cotton rotation in Alabama, by Mubarak et al. (2002) in Malaysia, and by Balkcom, et al. (2004) in Georgia.

Conclusions

Peanut residue decomposition occurred quickly regardless of placement and location. The amount of C that remained in the residue after one year on the soil surface did not significantly differ from buried residue. The data suggest that peanut residue under conservation tillage may not increase SOC compared to incorporated peanut residue, although conservation tillage systems that employ cover crops may contribute to SOC concentrations. Peanut residue did not contain significantly more N under conservation tillage than conventional tillage after a year. Although N fate was not determined in this study, there were no differences in potentially available N from peanut residue after a year of conservation tillage compared to conventional tillage at either the northern or southern limits of US peanut production. Warmer and moister climatic conditions in AL were likely responsible for the general lack of treatment differences at the WGS since the difference in microbial activity acting on residue at zero and 10 cm depth is likely to be less pronounced than those at NC. These data suggest that N credits are not warranted crops succeeding peanut because N is released too quickly for subsequent crop uptake.

Table 37. Analysis of variance for mass loss from peanut residue over the entire experiment.

Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Loc.	<0.0001	0.0193
Variety	<0.0001	<0.0001
Variety x Loc.	<0.0001	<0.0001
Placement	<0.0001	<0.0001
Placement x Loc.	0.0034	0.0044
Variety x Placement	0.3749	0.8904
Variety x Placement x Loc.	<0.0001	0.0133
Days(Loc.)	<0.0001	<0.0001
Days x Variety(Loc.)	0.0034	0.0002
Days x Placement(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 38. Analysis of variance for mass loss from peanut residue at two locations.

Location	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Variety	<0.0001	<0.0001
NC	Placement	<0.0001	<0.0001
NC	Variety x Placement	0.0005	0.0477
NC	Days(Loc.)	<0.0001	<0.0001
NC	Days x Variety(Loc.)	<0.0001	<0.0001
NC	Days x Placement(Loc.)	<0.0001	<0.0001
WGS	Variety	0.0280	0.8027
WGS	Placement	<0.0001	<0.0001
WGS	Variety x Placement	0.0312	0.1656
WGS	Days(Loc.)	<0.0001	<0.0001
WGS	Days x Variety(Loc.)	0.2323	0.1287
WGS	Days x Placement(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 39. Peanut residue mass loss analysis of variance for pairwise variety comparisons at two placements and two locations.

Location	Placement	Variety comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Surface	ANorden	GA 02-C	0.8408	0.3159
NC	Surface	ANorden	NC V-11	<0.0001	<0.0001
NC	Surface	GA 02-C	NC V-11	<0.0001	<0.0001
NC	Buried	ANorden	GA 02-C	0.7609	0.7302
NC	Buried	ANorden	NC V-11	<0.0001	0.0005
NC	Buried	GA 02-C	NC V-11	<0.0001	0.0002
WGS	Surface	ANorden	GA 02-C	0.0083	0.6860
WGS	Surface	ANorden	NC V-11	0.3980	0.2282
WGS	Surface	GA 02-C	NC V-11	0.0013	0.1151
WGS	Buried	ANorden	GA 02-C	0.4576	0.4015
WGS	Buried	ANorden	NC V-11	0.3063	0.7662
WGS	Buried	GA 02-C	NC V-11	0.7642	0.2601

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 40. Peanut residue mass loss analysis of variance for pairwise placement comparisons for three varieties and two locations.

Location	Variety	Placement comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	ANorden	Surface	Buried	<0.0001	<0.0001
NC	GA 02-C	Surface	Buried	<0.0001	<0.0001
NC	NC V-11	Surface	Buried	<0.0001	<0.0001
WGS	ANorden	Surface	Buried	0.0003	0.0105
WGS	GA 02-C	Surface	Buried	0.0338	0.1287
WGS	NC V-11	Surface	Buried	<0.0001	0.0003

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 41. Analysis of variance for mass loss from peanut residue at two placements.

Placement	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	Loc.	0.2601	0.0031
Surface	Variety	<0.0001	0.0209
Surface	Variety x Loc.	<0.0001	0.0001
Surface	Days(Loc.)	<0.0001	<0.0001
Surface	Days x Variety(Loc.)	0.0433	0.0114
Buried	Loc.	<0.0001	0.6007
Buried	Variety	<0.0001	0.0010
Buried	Variety x Loc.	<0.0001	0.0376
Buried	Days(Loc.)	<0.0001	<0.0001
Buried	Days x Variety(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 42. Peanut residue mass loss analysis of variance for pairwise location comparisons at two placements and three varieties.

Placement	Variety	Location comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	ANorden	NC	WGS	0.0112	0.0019
Surface	GA 02-C	NC	WGS	<0.0001	0.0001
Surface	NC V-11	NC	WGS	<0.0001	0.0198
Buried	ANorden	NC	WGS	0.2888	0.2101
Buried	GA 02-C	NC	WGS	0.6037	0.7515
Buried	NC V-11	NC	WGS	<0.0001	0.0211

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 43. Equations regressed on time (days) for mass loss on a per area basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
Mass buried (Mg ha^{-1}) NC				
ANorden	$Y = 1.59e^{-0.1560X} + 1.63e^{-0.0010X}$	0.0002	0.931	0.2
GA 02-C	$Y = 1.68e^{-0.0990X} + 1.51e^{-0.0010X}$	<0.0001	0.958	0.1
NC V-11	$Y = 1.68e^{-0.1660X} + 0.79e^{-0.0002X}$	0.0012	0.877	0.2
Mass surface (Mg ha^{-1}) NC				
ANorden	$Y = 1.02e^{-0.029X} + 2.30e^{-0.0006X}$	0.0003	0.926	0.2
GA 02-C	$Y = 0.94e^{-0.048X} + 2.40e^{-0.0006X}$	0.0011	0.879	0.2
NC V-11	$Y = 1.14e^{-0.149X} + 1.26$	0.0201	0.676	0.2
Mass buried (Mg ha^{-1}) WGS				
ANorden	$Y = 2.10e^{-0.130X} + 1.50e^{-0.003X}$	<0.0001	0.977	0.1
GA 02-C	$Y = 1.47e^{-0.120X} + 1.82e^{-0.003X}$	0.0182	0.752	0.5
NC V-11	$Y = 2.13e^{-0.077X} + 1.28e^{-0.002X}$	0.0020	0.900	0.3
Mass surface (Mg ha^{-1}) WGS				
ANorden	$Y = 1.72e^{-0.06X} + 1.99$	0.0007	0.933	0.2
GA 02-C	$Y = 2.00e^{-0.039X} + 1.40$	0.0144	0.774	0.4
NC V-11	$Y = 1.68e^{-0.029X} + 1.81$	0.0267	0.710	0.4

† Significance of regression; ‡ Standard error of the estimate of Y on X.

Table 44. Equations regressed on time (days) for mass loss on a percent basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
Mass buried (%) NC				
ANorden	$Y = 50.9e^{-0.1350X} + 47.9e^{-0.0005X}$	0.0005	0.908	5.9
GA 02-C	$Y = 53.7e^{-0.0980X} + 48.3e^{-0.0010X}$	<0.0001	0.958	4.8
NC V-11	$Y = 66.3e^{-0.1720X} + 32.7e^{-0.0005X}$	0.0014	0.869	8.7
Mass surface (%) NC				
ANorden	$Y = 28.6e^{-0.032X} + 73.8e^{-0.0007X}$	0.0004	0.911	5.1
GA 02-C	$Y = 27.3e^{-0.05X} + 79.5e^{-0.0007X}$	0.0011	0.881	5.6
NC V-11	$Y = 45.5e^{-0.149X} + 50.9$	0.0201	0.676	9.8
Mass buried (%) WGS				
ANorden	$Y = 58.0e^{-0.1270X} + 41.4e^{-0.0030X}$	<0.0001	0.977	4.1
GA 02-C	$Y = 44.5e^{-0.1200X} + 56.9e^{-0.0030X}$	0.0189	0.748	14.0
NC V-11	$Y = 59.3e^{-0.0770X} + 38.1e^{-0.0020X}$	0.0018	0.902	8.9
Mass surface (%) WGS				
ANorden	$Y = 47.2e^{-0.0610X} + 55.3$	0.0008	0.930	4.9
GA 02-C	$Y = 61.4e^{-0.0390X} + 43.2$	0.0152	0.770	12.7
NC V-11	$Y = 45.5e^{-0.0270X} + 52.9$	0.0258	0.713	10.8

† Significance of regression; ‡ Standard error of the estimate of Y on X.

Table 45. Analysis of variance for carbon loss from peanut residue over the entire experiment.

Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Loc.	0.3607	<0.0001
Variety	<0.0001	<0.0001
Variety x Loc.	<0.0001	<0.0001
Placement	<0.0001	<0.0001
Placement x Loc.	0.0002	0.0008
Variety x Placement	0.9800	0.9968
Variety x Placement x Loc.	0.0008	0.0148
Days(Loc.)	<0.0001	<0.0001
Days x Variety(Loc.)	<0.0001	<0.0001
Days x Placement(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 46. Analysis of variance for carbon loss from peanut residue at two locations.

Location	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Variety	<0.0001	<0.0001
NC	Placement	<0.0001	<0.0001
NC	Variety x Placement	0.0029	0.0436
NC	Days(Loc.)	<0.0001	<0.0001
NC	Days x Variety(Loc.)	<0.0001	<0.0001
NC	Days x Placement(Loc.)	<0.0001	<0.0001
NC	Days x Placement x Variety(Loc.)	0.4251	0.6556
WGS	Variety	0.0073	0.2422
WGS	Placement	0.0599	0.1532
WGS	Variety x Placement	0.0845	0.2081
WGS	Days(Loc.)	<0.0001	<0.0001
WGS	Days x Variety(Loc.)	0.0332	0.0155
WGS	Days x Placement(Loc.)	<0.0001	<0.0001
WGS	Days x Placement x Variety(Loc.)	0.0230	0.0155

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 47. Peanut residue carbon loss analysis of variance for pairwise placement comparisons for three varieties and two locations.

Location	Variety	Placement comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	ANorden	Surface	Buried	<0.0001	<0.0001
NC	GA 02-C	Surface	Buried	<0.0001	<0.0001
NC	NC V-11	Surface	Buried	0.0105	0.0089
WGS	ANorden	Surface	Buried	0.7879	0.8203
WGS	GA 02-C	Surface	Buried	0.9545	0.9659
WGS	NC V-11	Surface	Buried	0.0066	0.0298

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 48. Peanut residue carbon loss analysis of variance for pairwise variety comparisons at two placements and two locations.

Location	Placement	Variety comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Surface	ANorden	GA 02-C	0.6615	0.3888
NC	Surface	ANorden	NC V-11	<0.0001	<0.0001
NC	Surface	GA 02-C	NC V-11	<0.0001	<0.0001
NC	Buried	ANorden	GA 02-C	0.6413	0.6374
NC	Buried	ANorden	NC V-11	<0.0001	0.0002
NC	Buried	GA 02-C	NC V-11	<0.0001	<0.0001
WGS	Surface	ANorden	GA 02-C	0.0535	0.2047
WGS	Surface	ANorden	NC V-11	0.0801	0.4081
WGS	Surface	GA 02-C	NC V-11	0.0011	0.0447
WGS	Buried	ANorden	GA 02-C	0.0827	0.3137
WGS	Buried	ANorden	NC V-11	0.3534	0.2151
WGS	Buried	GA 02-C	NC V-11	0.3912	0.8024

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 49. Analysis of variance for carbon loss from peanut residue at two placements.

Placement	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	Loc.	0.0048	<0.0001
Surface	Variety	<0.0001	0.0101
Surface	Variety x Loc.	<0.0001	<0.0001
Surface	Days(Loc.)	<0.0001	<0.0001
Surface	Days x Variety(Loc.)	0.0029	0.0027
Buried	Loc.	0.0208	0.4821
Buried	Variety	<0.0001	0.0009
Buried	Variety x Loc.	<0.0001	0.0198
Buried	Days(Loc.)	<0.0001	<0.0001
Buried	Days x Variety(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 50. Peanut residue carbon loss analysis of variance for pairwise location comparisons at two placements and three varieties.

Placement	Variety	Location comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	ANorden	NC	WGS	<0.0001	0.0003
Surface	GA 02-C	NC	WGS	<0.0001	<0.0001
Surface	NC V-11	NC	WGS	<0.0001	0.0631
Buried	ANorden	NC	WGS	0.6310	0.5066
Buried	GA 02-C	NC	WGS	0.0189	0.0216
Buried	NC V-11	NC	WGS	<0.0001	0.0736

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 51. Equations regressed on time (days) for carbon loss on a per area basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
C buried (Mg ha^{-1}) NC				
ANorden	$Y = 0.608e^{-0.1560X} + 0.698e^{-0.0020X}$	0.0016	0.862	0.1
GA 02-C	$Y = 0.663e^{-0.0970X} + 0.622e^{-0.0020X}$	0.0002	0.930	0.1
NC V-11	$Y = 0.717e^{-0.1500X} + 0.279e^{-0.0005X}$	0.0008	0.892	0.1
C surface (Mg ha^{-1}) NC				
ANorden	$Y = 0.459e^{-0.0330X} + 0.904e^{-0.0020X}$	0.0009	0.889	0.1
GA 02-C	$Y = 0.339e^{-0.0560X} + 1.005^{e-0.0030X}$	0.0013	0.874	0.1
NC V-11	$Y = 0.558e^{-0.0860X} + 0.381e^{-0.0010X}$	0.0046	0.805	0.1
C surface (Mg ha^{-1}) WGS				
ANorden	$Y = 0.928e^{-0.0490X} + 0.542e^{-0.0030X}$	0.0007	0.895	0.2
GA 02-C	$Y = 1.055e^{-0.0330X} + 0.243e^{-0.0010X}$	0.0001	0.946	0.1
NC V-11	$Y = 0.909e^{-0.0290X} + 0.505e^{-0.0020X}$	0.0020	0.852	0.2
C buried (Mg ha^{-1}) WGS				
ANorden	$Y = 0.86e^{-0.103X} + 0.495e^{-0.003X}$	0.0004	0.947	0.1
GA 02-C	$Y = 0.69e^{-0.132X} + 0.597e^{-0.004X}$	0.0051	0.852	0.1
NC V-11	$Y = 0.81e^{-0.102X} + 0.527e^{-0.003X}$	0.0022	0.896	0.1

† Significance of regression; ‡ Standard error of the estimate of Y on X.

Table 52. Equations regressed on time (days) for carbon loss on a percent basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
C buried (%) NC				
ANorden	$Y = 46.2e^{-0.1510X} + 53.0e^{-0.0020X}$	0.0016	0.864	8.4
GA 02-C	$Y = 51.9e^{-0.0970X} + 49.8e^{-0.0020X}$	0.0002	0.929	6.8
NC V-11	$Y = 70.9e^{-0.1490X} + 27.5e^{-0.0005X}$	0.0008	0.892	8.4
C surface (%) NC				
ANorden	$Y = 33.2e^{-0.0340X} + 70.3e^{-0.0020X}$	0.0011	0.879	9.2
GA 02-C	$Y = 24.7e^{-0.0570X} + 81.8e^{-0.0030X}$	0.0009	0.886	9.0
NC V-11	$Y = 55.1e^{-0.0860X} + 37.8e^{-0.0010X}$	0.0046	0.805	10.8
C buried (%) WGS				
ANorden	$Y = 64.0e^{-0.0970X} + 36.4e^{-0.0020X}$	0.0005	0.944	6.9
GA 02-C	$Y = 52.4e^{-0.1320X} + 47.0e^{-0.0040X}$	0.0050	0.853	11.0
NC V-11	$Y = 50.3e^{-0.1870X} + 48.4e^{-0.0050X}$	0.0024	0.892	9.2
C surface (%) WGS				
ANorden	$Y = 67.9e^{-0.0480X} + 41.4e^{-0.0040X}$	0.0008	0.891	12.2
GA 02-C	$Y = 81.0e^{-0.0330X} + 19.1e^{-0.0010X}$	0.0001	0.941	8.6
NC V-11	$Y = 67.4e^{-0.0250X} + 32.0e^{-0.0010X}$	0.0015	0.866	11.7

† Significance of regression; ‡ Standard error of the estimate of Y on X.

Table 53. Analysis of variance for nitrogen loss from peanut residue over the entire experiment.

Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Loc.	0.0338	0.0767
Variety	<0.0001	0.0063
Variety x Loc.	<0.0001	0.0005
Placement	0.0429	0.2259
Placement x Loc.	0.0002	0.0216
Variety x Placement	0.9696	0.9977
Variety x Placement x Loc.	0.1313	0.6037
Days(Loc.)	<0.0001	<0.0001
Days x Variety(Loc.)	<0.0001	<0.0001
Days x Placement(Loc.)	<0.0001	<0.0001
Days xVariety x Placement(Loc.)	0.0035	0.0063

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 54. Analysis of variance for nitrogen loss from peanut residue at two locations.

Location	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Variety	<0.0001	<0.0001
NC	Placement	<0.0001	0.0083
NC	Variety x Placement	0.1086	0.7250
NC	Days(Loc.)	<0.0001	<0.0001
NC	Days x Variety(Loc.)	<0.0001	<0.0001
NC	Days x Placement(Loc.)	0.0628	0.0652
NC	Days x Variety x Placement(Loc.)	0.8219	0.8765
WGS	Variety	0.0064	0.5639
WGS	Placement	0.2457	0.4588
WGS	Variety x Placement	0.5564	0.8059
WGS	Days(Loc.)	<0.0001	<0.0001
WGS	Days x Variety(Loc.)	0.0020	0.0256
WGS	Days x Placement(Loc.)	<0.0001	<0.0001
WGS	Days x Variety x Placement(Loc.)	<0.0001	0.0074

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 55. Peanut residue nitrogen loss analysis of variance for pairwise placement comparisons for three varieties and two locations.

Location	Variety	Placement comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	ANorden	Surface	Buried	0.0001	0.0487
NC	GA 02-C	Surface	Buried	0.0006	0.0509
NC	NC V-11	Surface	Buried	0.0981	0.3209
WGS	ANorden	Surface	Buried	0.1655	0.3828
WGS	GA 02-C	Surface	Buried	0.4235	0.6272
WGS	NC V-11	Surface	Buried	0.8472	0.9305

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 56. Peanut residue nitrogen loss analysis of variance for pairwise variety comparisons at two placements and two locations.

Location	Placement	Variety comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
NC	Surface	ANorden	GA 02-C	0.5068	0.6967
NC	Surface	ANorden	NC V-11	<0.0001	0.0004
NC	Surface	GA 02-C	NC V-11	<0.0001	0.0007
NC	Buried	ANorden	GA 02-C	0.1708	0.7908
NC	Buried	ANorden	NC V-11	<0.0001	0.0046
NC	Buried	GA 02-C	NC V-11	<0.0001	0.0070
WGS	Surface	ANorden	GA 02-C	0.2829	0.6793
WGS	Surface	ANorden	NC V-11	0.3720	0.5441
WGS	Surface	GA 02-C	NC V-11	0.0596	0.3136
WGS	Buried	ANorden	GA 02-C	0.6475	0.4224
WGS	Buried	ANorden	NC V-11	0.0203	0.7207
WGS	Buried	GA 02-C	NC V-11	0.0073	0.6535

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 57. Analysis of variance for nitrogen loss from peanut residue at two placements.

Placement	Effect	P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	Loc.	0.0005	0.0055
Surface	Variety	<0.0001	0.0625
Surface	Variety x Loc.	<0.0001	0.0037
Surface	Days(Loc.)	<0.0001	<0.0001
Surface	Days x Variety(Loc.)	0.0005	0.0018
Buried	Loc.	0.1548	0.6990
Buried	Variety	<0.0001	0.0969
Buried	Variety x Loc.	0.0002	0.0956
Buried	Days(Loc.)	<0.0001	<0.0001
Buried	Days x Variety(Loc.)	<0.0001	<0.0001

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 58. Peanut residue nitrogen loss analysis of variance for pairwise location comparisons at two placements and three varieties.

Placement	Variety	Location comparison		P>F (mass area^{-1})†	P>F (% basis) ‡
Surface	ANorden	NC	WGS	<0.0001	0.0031
Surface	GA 02-C	NC	WGS	<0.0001	0.0028
Surface	NC V-11	NC	WGS	0.0028	0.1824
Buried	ANorden	NC	WGS	0.3025	0.7245
Buried	GA 02-C	NC	WGS	0.1270	0.3077
Buried	NC V-11	NC	WGS	<0.0001	0.0537

† P>F values based on data analyzed on a per area basis; ‡ P>F values based on data analyzed on a percent remaining basis, where day 0 = 100%.

Table 59. Equations regressed on time (days) for nitrogen loss on a per area basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx} ‡
N buried (kg ha^{-1}) NC				
ANorden	$Y = 10.7e^{-1.3200X} + 48.0e^{-0.0020X}$	0.0491	0.559	7.4
GA 02-C	$Y = 17.1e^{-0.1330X} + 47.8e^{-0.0020X}$	0.0028	0.835	5.2
NC V-11	$Y = 25.2e^{-0.1800X} + 16.9$	0.0184	0.686	5.2
N surface (kg ha^{-1}) NC				
ANorden	$Y = 54.2e^{-0.0020X} + 5.8$	0.0158	0.702	6.5
GA 02-C	$Y = 29.0e^{-0.0020X} + 31.6e^{-0.0020X}$	0.0272	0.641	7.0
NC V-11	$Y = 16.8e^{-0.6380X} + 25.8e^{-0.0010X}$	0.0541	0.544	5.8
N buried (kg ha^{-1}) WGS				
ANorden	$Y = 27.7e^{-0.1400X} + 32.8e^{-0.0020X}$	0.0104	0.803	6.5
GA 02-C	$Y = 29.6e^{-0.0840X} + 39.0e^{-0.0030X}$	0.0327	0.684	10.9
NC V-11	$Y = 26.3e^{-0.0600X} + 23.0e^{-0.0008X}$	<0.0001	0.976	1.8
N surface (kg ha^{-1}) WGS				
ANorden	$Y = 28.1e^{-0.0560X} + 35.5e^{-0.0020X}$	0.0053	0.850	6.7
GA 02-C	$Y = 53.7e^{-0.0230X} + 17.3e^{-0.0009X}$	0.0117	0.793	11.2
NC V-11	$Y = 28.6e^{-0.0160X} + 19.7$	0.0254	0.715	6.6

† Significance of regression; ‡ Standard error of the estimate of Y on X.

Table 60. Equations regressed on time (days) for nitrogen loss on a percent basis from three varieties of peanut residue incubated in litter bags under field conditions. Double exponential decay equations are of the form $Y = Ae^{-k_1 t} + Be^{-k_2 t}$, where Y = mass loss, A = the labile portion, B = the recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t = time in days after application.

Parameter/Variety	Equation	P>F†	$R^2_{adj.}$	S_{yx}‡
N buried (%) NC				
ANorden	$Y = 17.1e^{-1.3470X} + 82.9e^{-0.0020X}$	0.0570	0.535	13.0
GA 02-C	$Y = 25.1e^{-0.1260X} + 77.2e^{-0.0020X}$	0.0034	0.824	8.4
NC V-11	$Y = 58.5e^{-0.1830X} + 40.4$	0.0205	0.674	12.4
N surface (%) NC				
ANorden	$Y = 90.2e^{-0.0020X} + 12.9$	0.0194	0.680	11.4
GA 02-C	$Y = 47.0e^{-0.0020X} + 50.7e^{-0.0020X}$	0.0304	0.627	11.7
NC V-11	$Y = 40.6e^{-0.3570X} + 58.7e^{-0.0010X}$	0.0572	0.535	13.9
N buried (%) WGS				
ANorden	$Y = 47.9e^{-0.1240X} + 56.2e^{-0.0020X}$	0.0175	0.756	12.6
GA 02-C	$Y = 43.6e^{-0.0850X} + 60.8e^{-0.0030X}$	0.0376	0.665	17.2
NC V-11	$Y = 51.3e^{-0.0580X} + 48.3e^{-0.0009X}$	0.0001	0.967	4.2
N surface (%) WGS				
ANorden	$Y = 44.4e^{-0.054X} + 64.7e^{-0.00300X}$	0.0079	0.824	12.7
GA 02-C	$Y = 80.1e^{-0.0250X} + 28.3e^{-0.0009X}$	0.0036	0.819	15.8
NC V-11	$Y = 59.3e^{-0.0140X} + 36.9$	0.0112	0.735	13.4

† Significance of regression; ‡ Standard error of the estimate of Y on X.

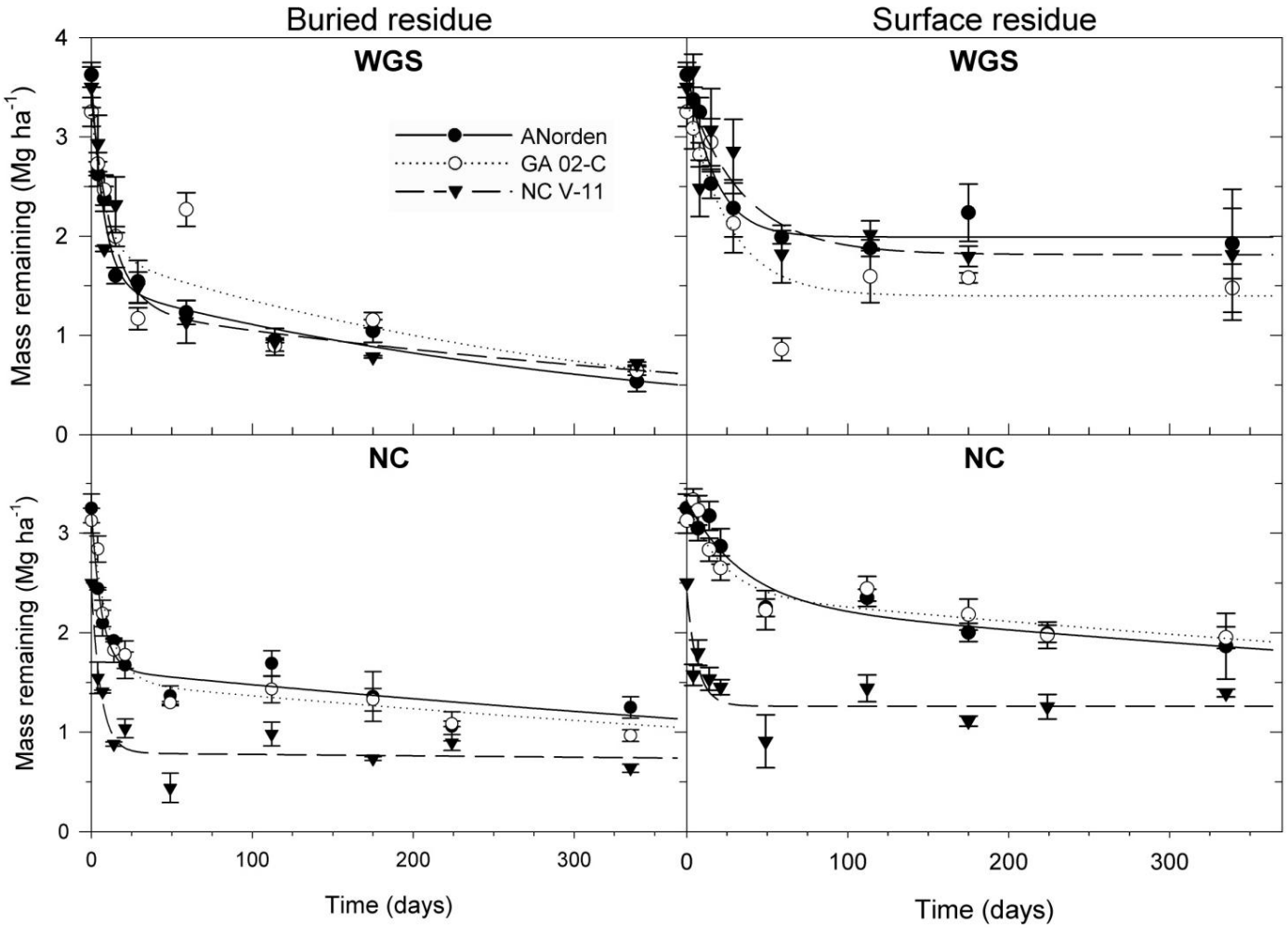

Figure 12. Mass loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a per area basis. Error bars represent standard errors of the mean.

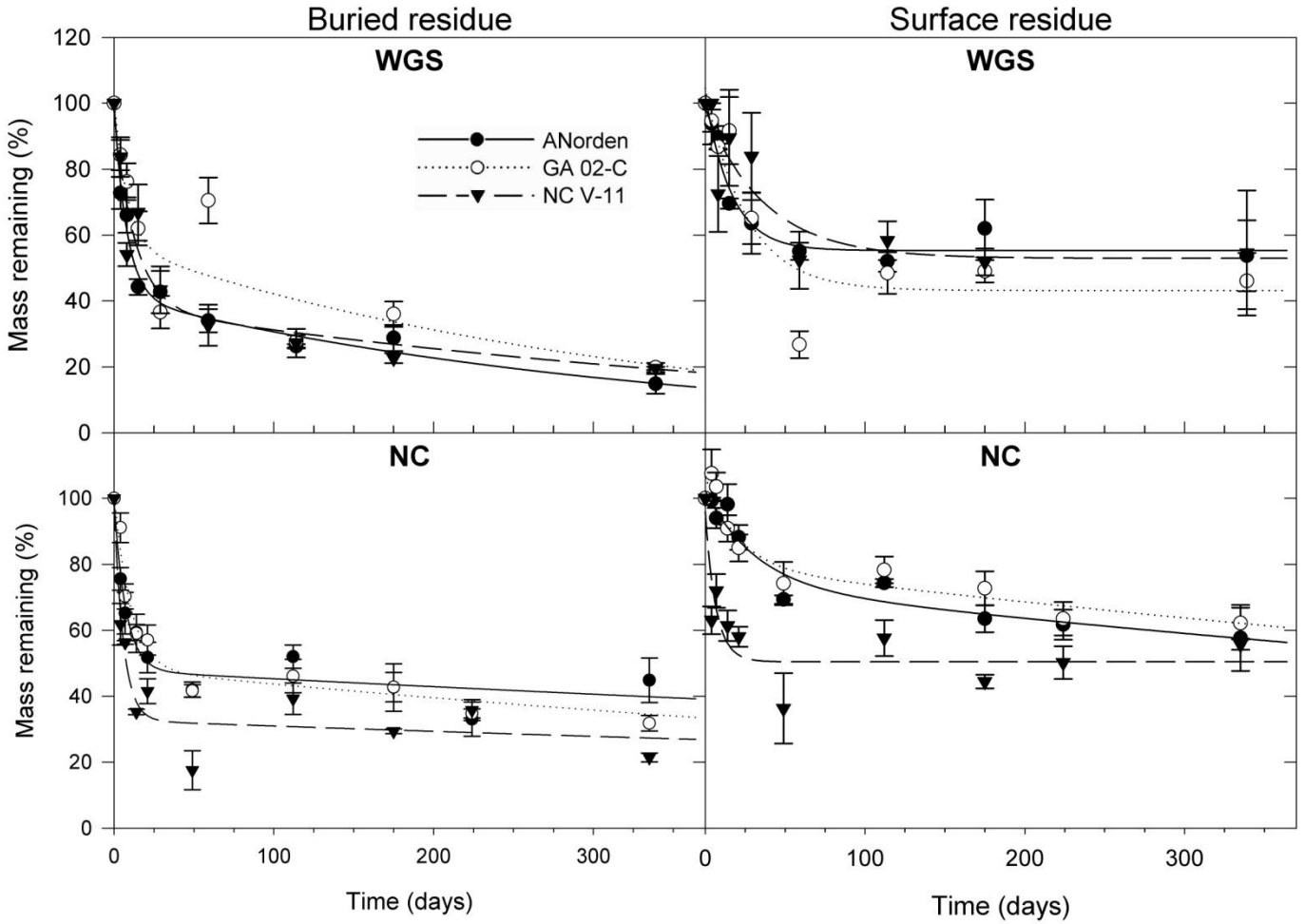

Figure 13. Mass loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a percent basis. Error bars represent standard errors of the mean.

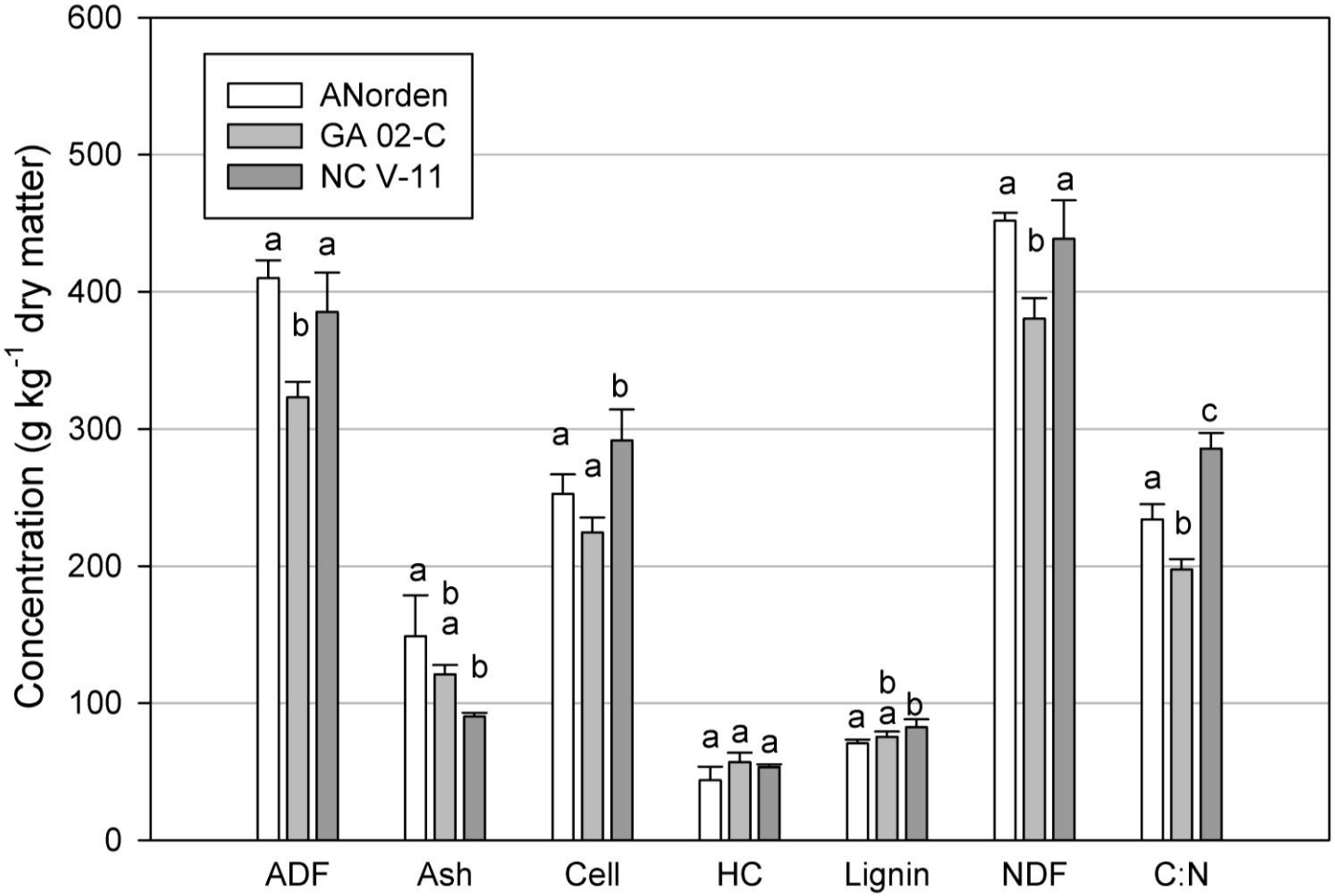

Figure 14. Fiber analysis of three peanut varieties grown and decomposed at the WGS site. The C:N data is a ratio, and is not shown as a concentration of dry matter. Error bars represent standard errors of the mean.

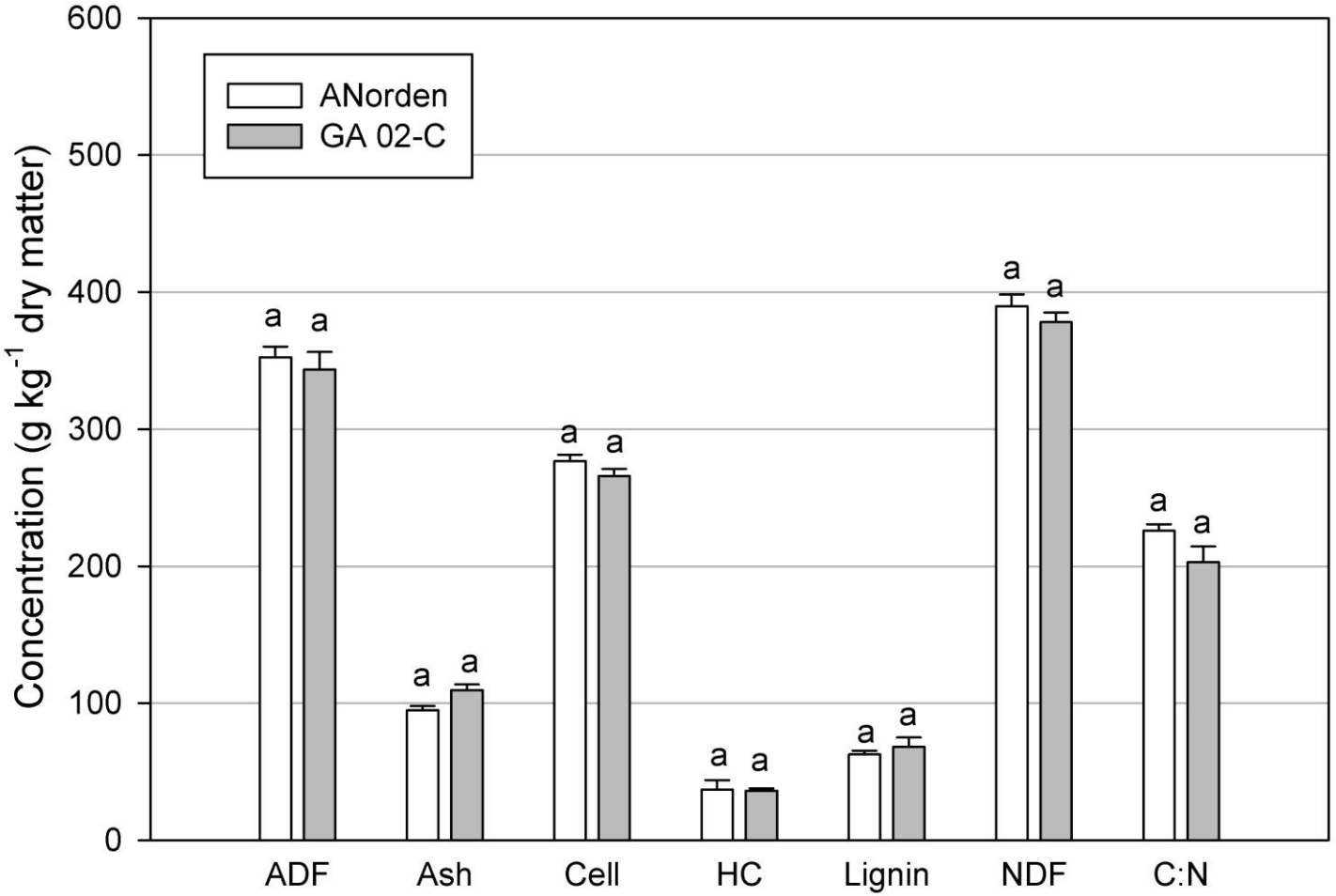

Figure 15. Fiber analysis of three peanut varieties grown and decomposed at the NC site. The C:N data is a ratio, and is not shown as a concentration of dry matter. Error bars represent standard errors of the mean.

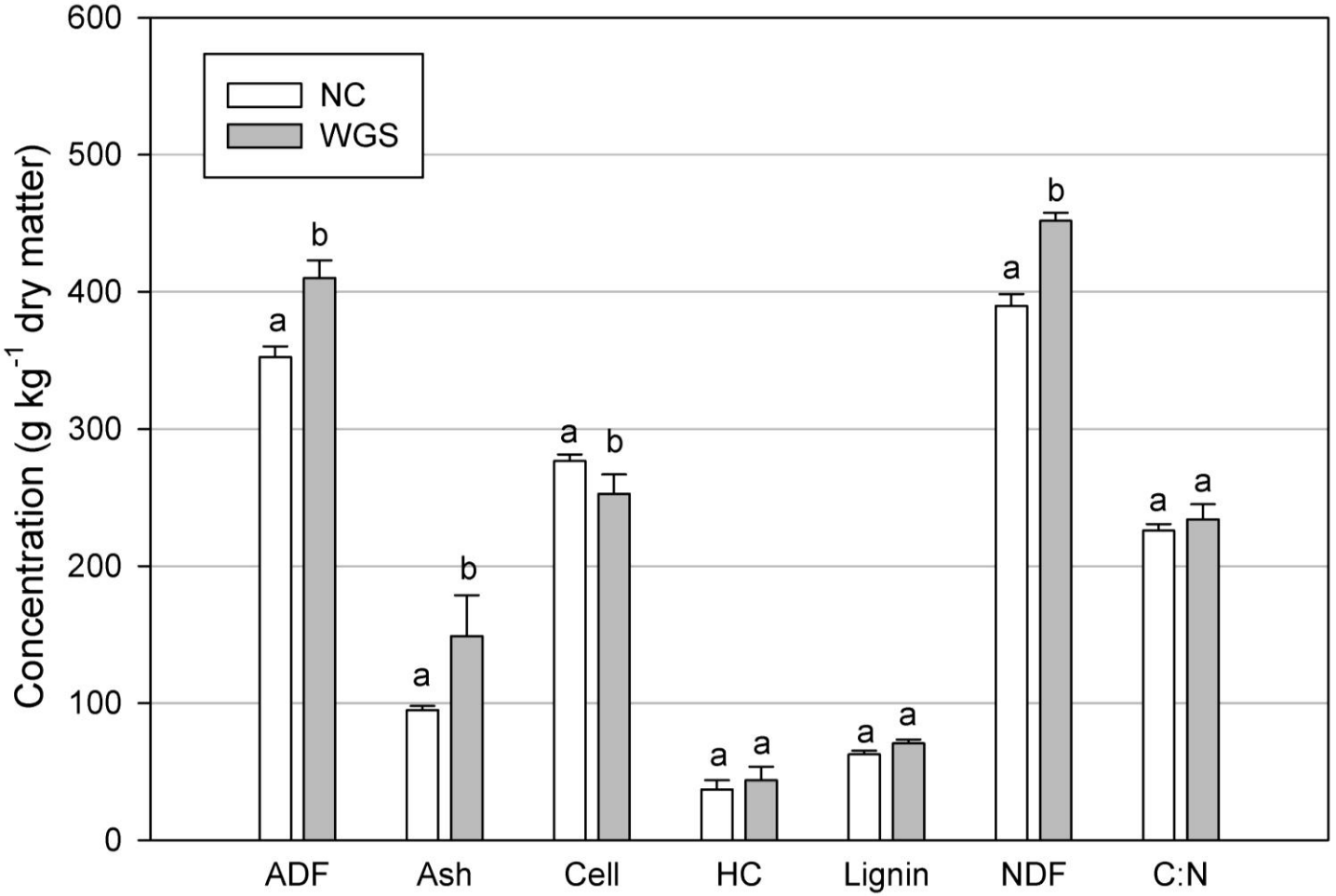

Figure 16. Fiber analysis of peanut variety ANorden grown at two sites. The C:N data is a ratio, and is not shown as a concentration of dry matter. Error bars represent standard errors of the mean.

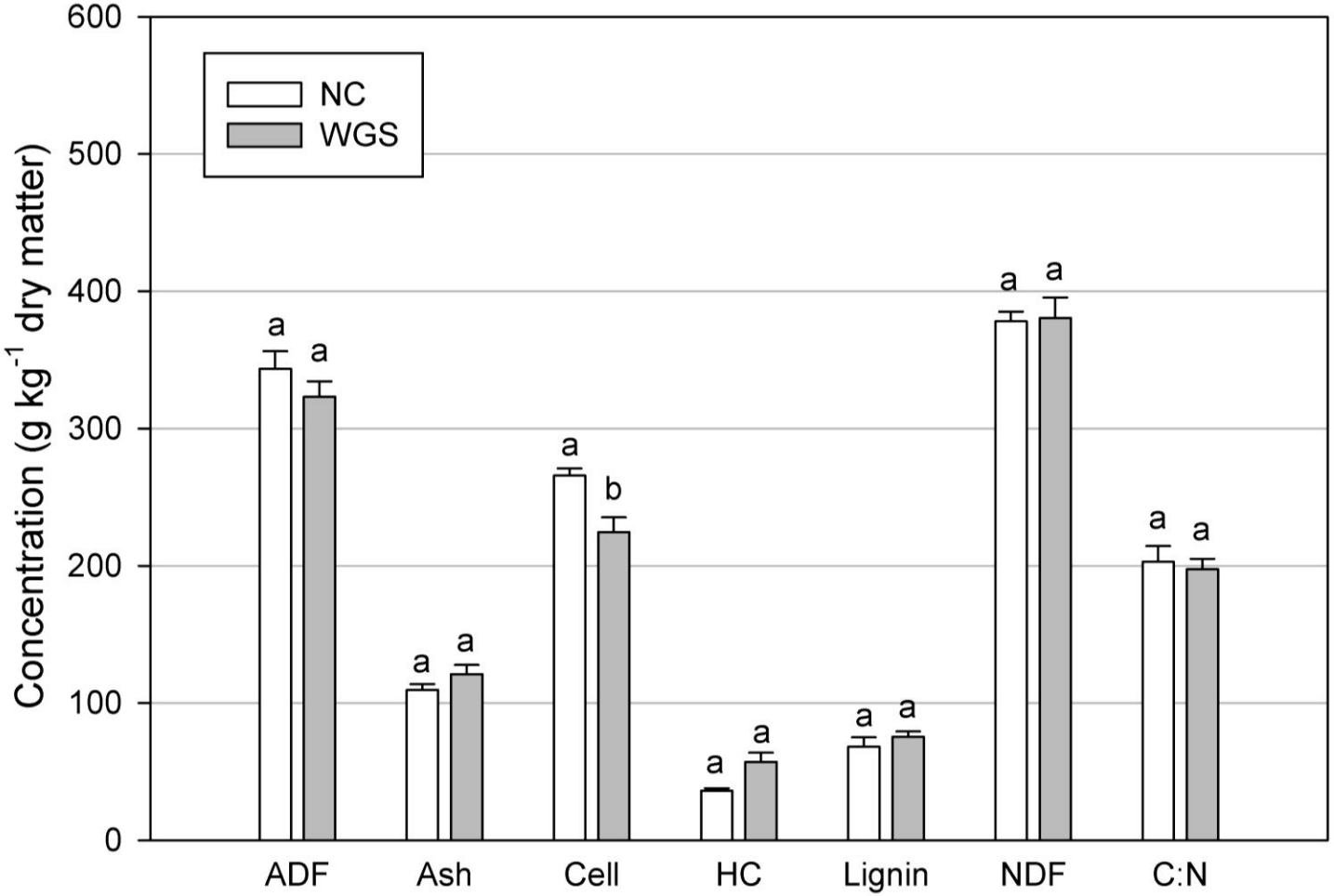

Figure 17. Fiber analysis of peanut variety GA 02-C grown at two sites. The C:N data is a ratio, and is not shown as a concentration of dry matter. Error bars represent standard errors of the mean.

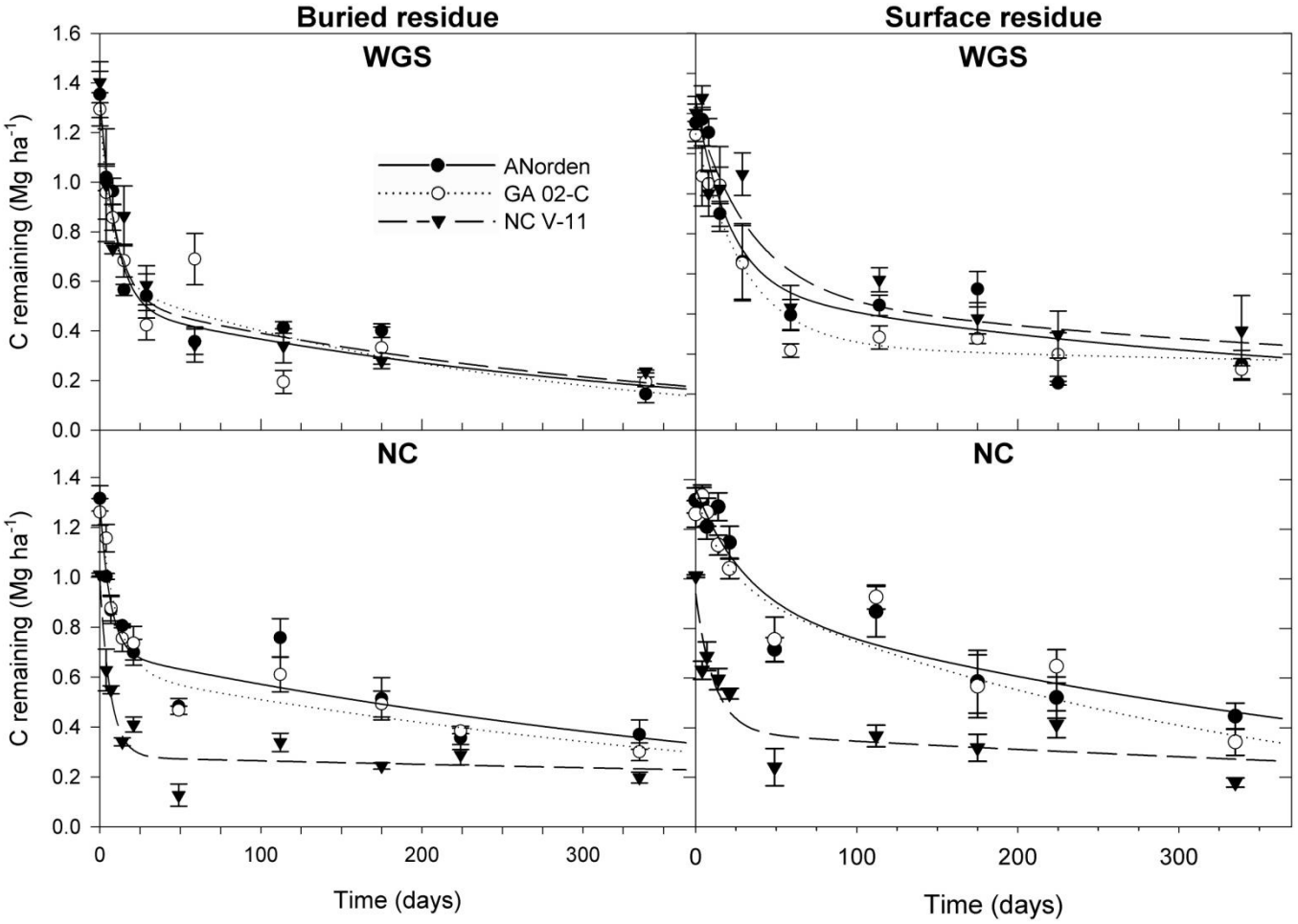

Figure 18. Carbon loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a per area basis. Error bars represent standard errors of the mean.

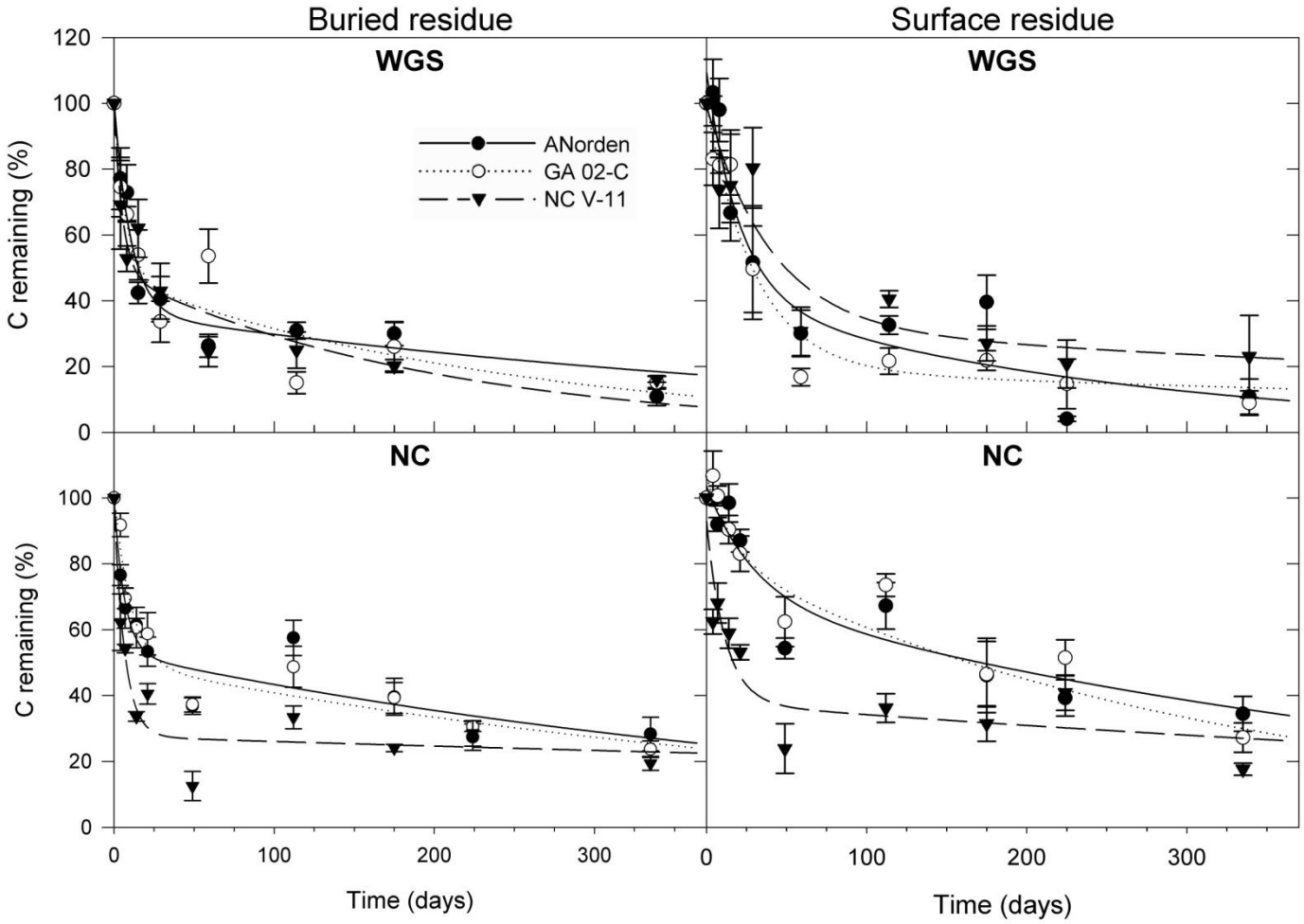

Figure 19. Carbon loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a percent basis. Error bars represent standard errors of the mean.

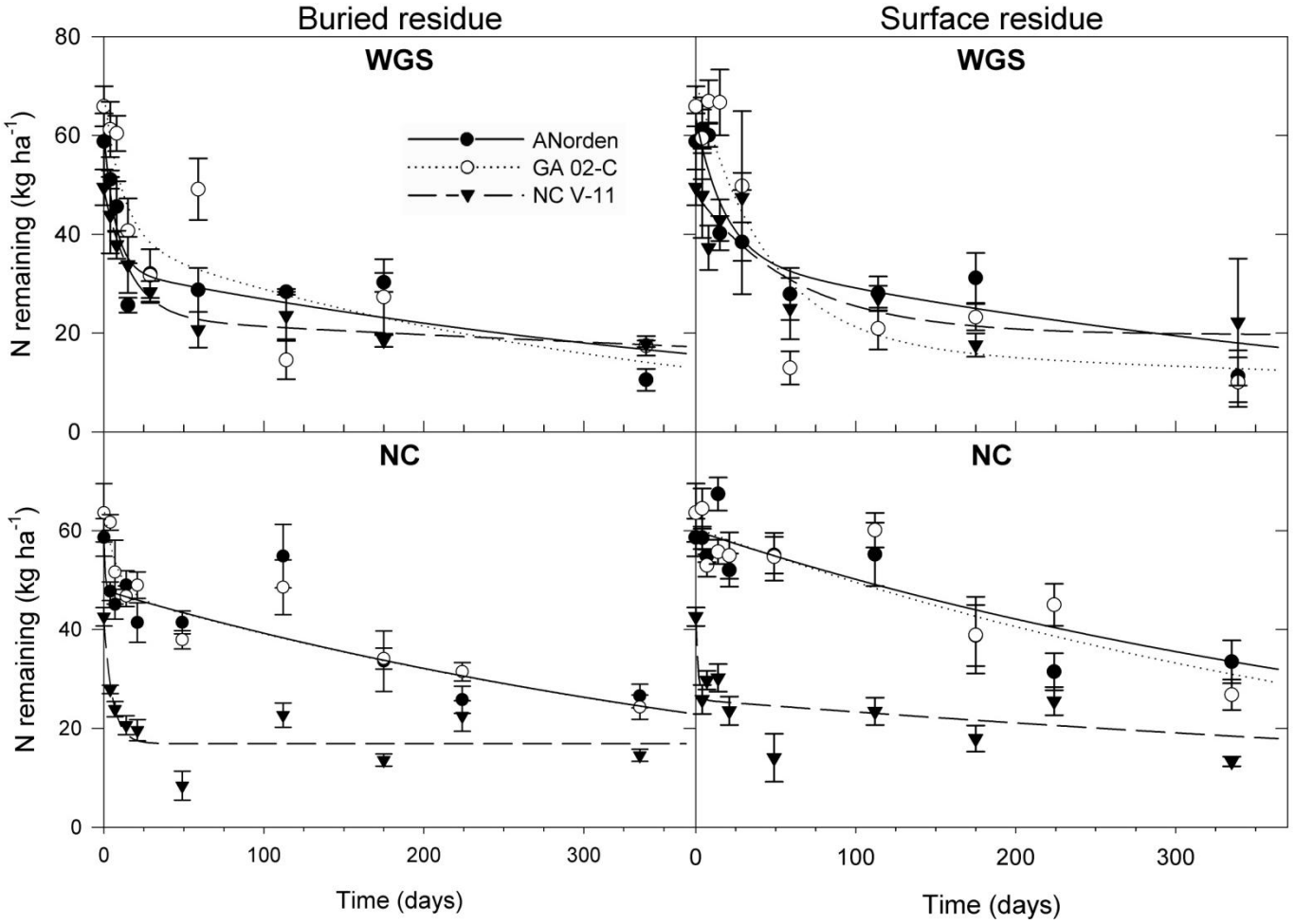

Figure 20. Nitrogen loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a per area basis. Error bars represent standard errors of the mean.

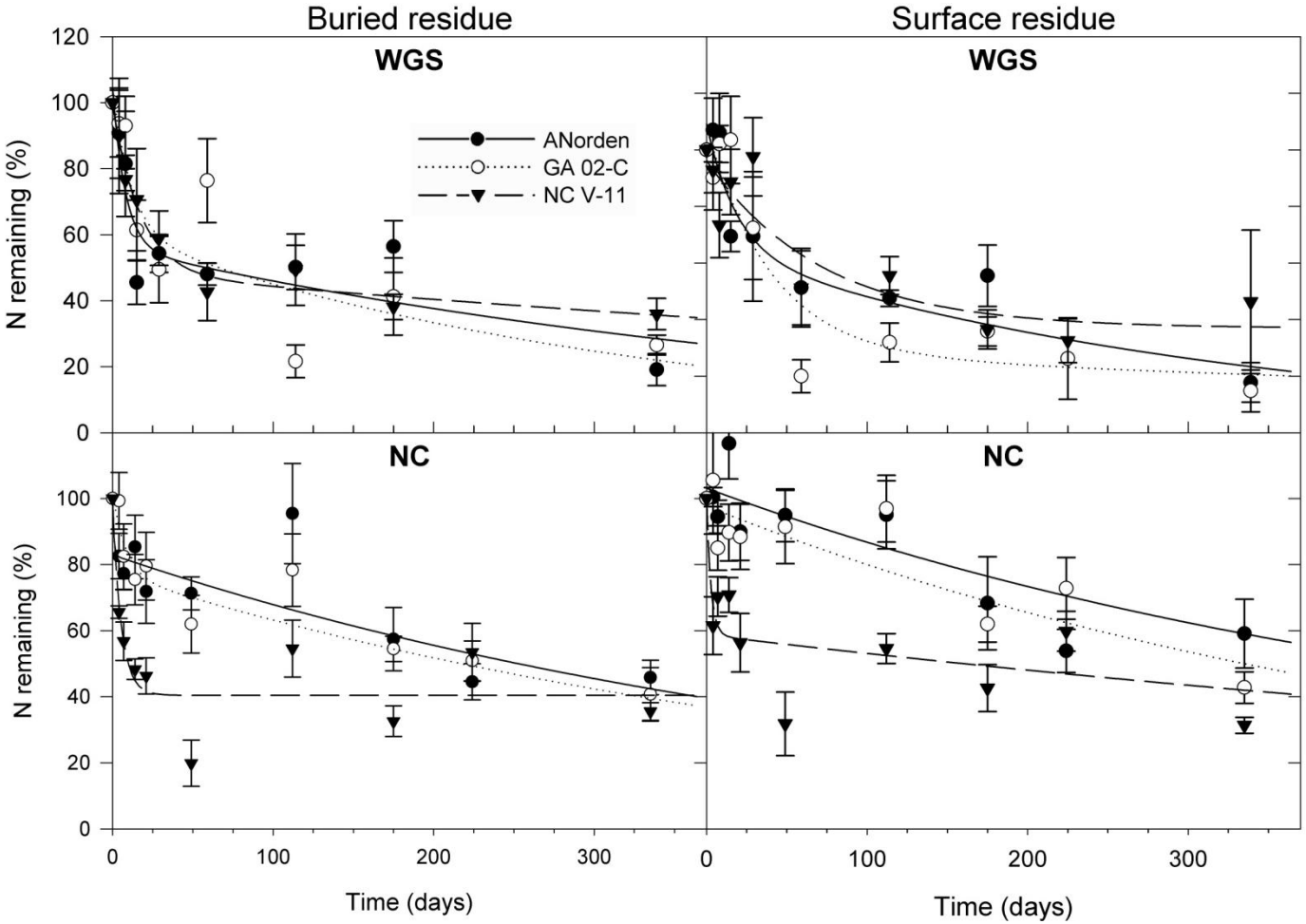

Figure 21. Nitrogen loss from three peanut residue varieties at two locations under conservation and conventional tillage, shown on a percent basis. Error bars represent standard errors of the mean.

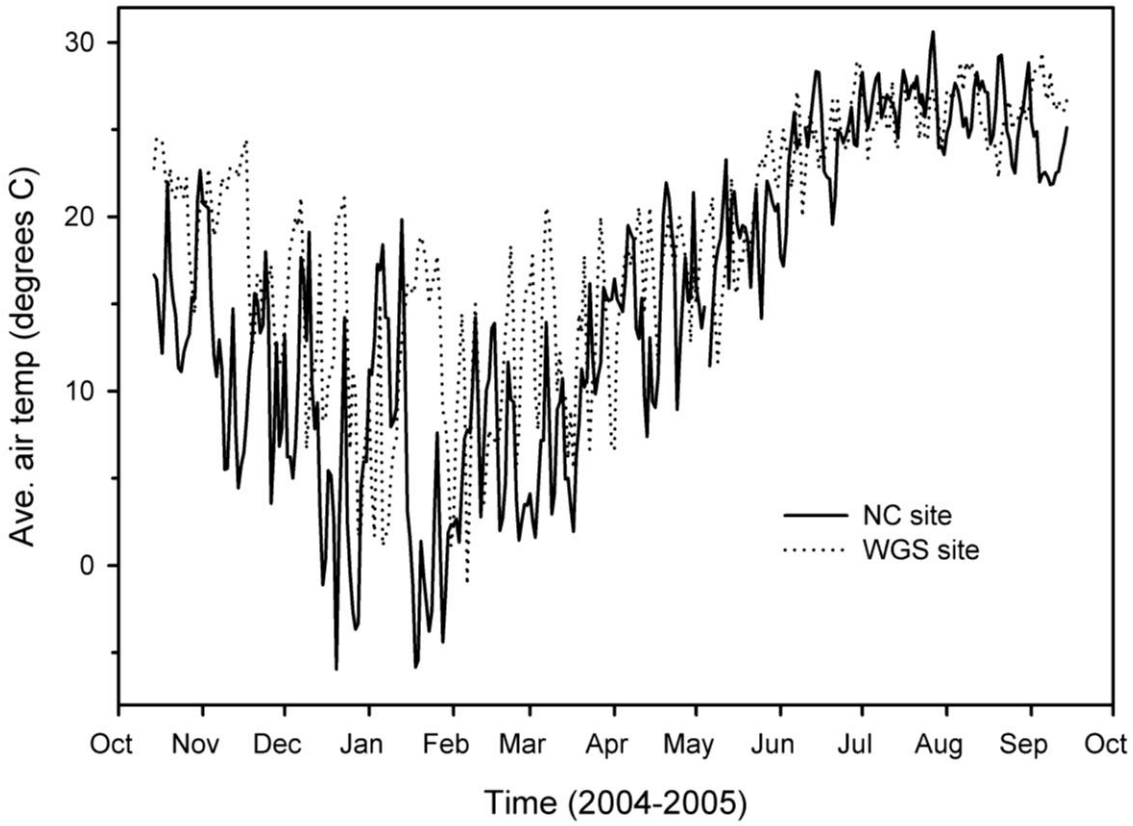

Figure 22. Average air temperature at 2 m at the two study sites.

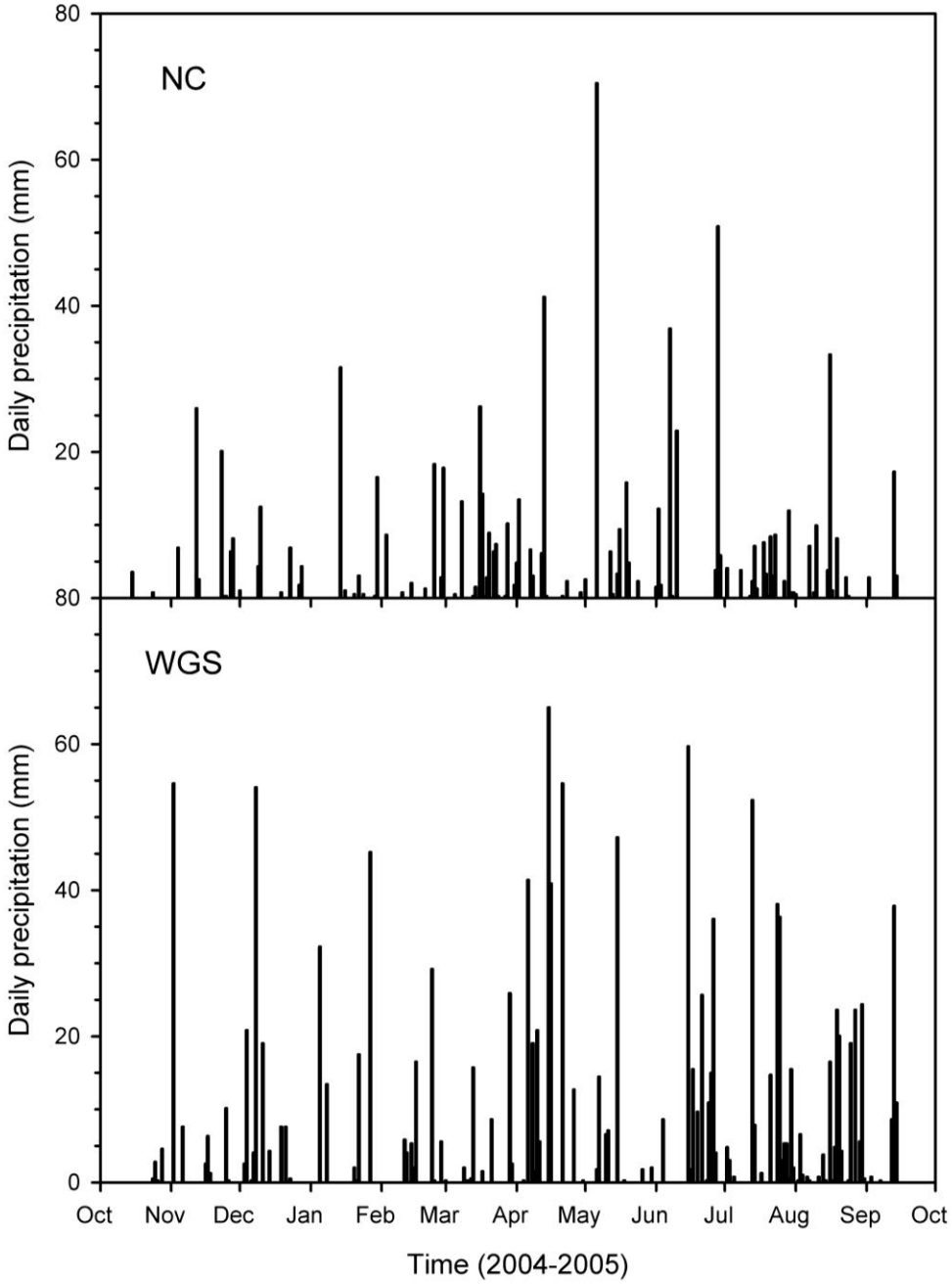

Figure 23. Daily precipitation at the two study sites.

V. Carbon and Nitrogen Mineralization of Peanut Residues in a Dothan Sandy Loam Soil

Abstract

Conservation tillage peanut production is gaining popularity among US peanut (*Arachis hypogaea* L.) producers. There is a question, however, as to how much nitrogen (N) is available to subsequent crops after peanut residue is left on the soil surface. The objective of this study was to determine N and carbon (C) mineralization rates from peanut tissue under conditions representing conservation and conventional tillage on a Dothan sandy loam 0-2% slopes (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults). A laboratory incubation study was conducted over 252 d in order to determine C and N mineralization rates compared to a soil-only control. Treatments included three peanut varieties (ANorden, GA 02-C, and NC V-11), three residue types (leaves, stems, and a 1:1 mixture of leaves to stems), and two residue placements (incorporated or surface placed) at a rate equivalent to 3.88 Mg ha^{-1}. Net N mineralization was not different between peanut varieties and the soil-only control during the 252 day incubation, although C mineralization was increased by the addition of peanut residues compared to the control. Although not statistically significant, peanut stems immobilized a small amount of N during the first 50 days of incubation. Compared to the control, peanut leaves mineralized net N after 50 d. No differences in C mineralization or net N mineralization were found between surface placed and

incorporated residue. Cumulative C turnover was 10.5-14.9% for amended soils, compared to 7.1% from the control over the same period. After 252 days, relative N mineralized from residue amended soils ranged from 9.2-12.8% compared to 11.2% from the control, suggesting that relative N mineralized from peanut residue was minimal. These data suggest that N mineralization from peanut residue is not sufficient to warrant N credits on a Dothan sandy loam soil.

Introduction

Conservation tillage has become a popular practice among US peanut growers in recent years (USDA, 2008d). Peanut residue is considered high-quality because of its low C:N content, low lignin content, and easy digestibility. The practice of leaving peanut residue in the field has raised questions about possible N contributions or credits to succeeding crops as residual N becomes mineralized. Conservation tillage is known to delay decomposition of residue and therefore N mineralization, and may delay N mineralization long enough to provide more N to succeeding crops than residue under conventional tillage systems.

Since plant parts consist of differing amounts of C, N, lignin, polyphenols, and other components, they decompose at differing rates (Stroo et al., 1989; Thippayarugs et al., 2008), and differing qualities of residue types can have synergistic or antagonistic effects on net N mineralization or immobilization (Thippayarugs et al., 2008). Previous work on a soil from Northeast Thailand showed that neither peanut stems, leaves nor a mixture of leaves and stems immobilized N over the duration of a 133 d study, while N was immobilized when pigeon pea (*Cajanus cajan* (L.) Millsp.) and hairy indigo

(*Indigofera hirsuta* L.) stems or roots were used as a substrate (Thippayarugs et al., 2008).

The implication that peanut stems do not cause net N immobilization in the short term may problematic for conservation tillage peanut producers wishing to synchronize N with subsequent crops. Since the majority of residue remaining on the soil surface after peanut harvest is stems (Thippayarugs et al., 2008), the possibility that N mineralization is fast, even from stems, can have implications for producers who may be inclined to reduce N fertilization following peanut. However, studies in the southeastern US have shown that peanut residue can immobilize or mineralize net N depending on the soil type and initial soil conditions (Balkcom et al., 2004). Soils with high C:N ratios are more likely to immobilize N than those with adequate amounts of N to meet both plant and microbial demands. Previous laboratory incubations on eight soil types with various residues, including peanut, showed that soil type was not a significant variable during N mineralization on Oklahoma soils (Smith and Sharpley, 1990).

Carbon mineralization rates of crop residues affect the soil C:N ratio and therefore have important implications for N availability as well as soil organic carbon (SOC) accumulation. However, there is a paucity of data on C mineralization from peanut residue. To date, no studies on C mineralization from peanut residue have been conducted sufficiently long to determine the time required to achieve equilibrium. Research conducted by Iyamuremye et al. (2000) showed that peanut residue mineralized approximately 500-600 mg more CO_2-C kg^{-1} soil than a soil-only control on a Senegalese soil after 12 weeks of incubation, but at that time C mineralization was still increasing faster than the control. While Balkcom et al. (2004) also showed that C from peanut

residue was mineralized faster than soil-only controls, the study was terminated after 98 d while mineralization rates were still increasing dramatically. During that time, C turnover with residues added to soil reached 18-19%, while the soil-only control turned over only 6.5% of total C.

While the peanut mineralization studies conducted by Balkcom et al. (2004) were conducted on two extreme soil types (Tifton and Greenville soils) of the peanut producing area in the US the Dothan soil series comprises over 723,000 hectares stretching over the entire peanut producing region of the US, from the Florida panhandle to central North Carolina, and even into southern Virginia (USDA, 2008a). Peanut residue mineralization patterns on this common soil type have yet to be determined. The objective of this study was to determine net N and C mineralization rates from the stems, leaves, and a mixture of leaves and stems from three peanut varieties under conditions representing conservation and conventional tillage on a Dothan soil series.

Materials and Methods

Experimental design

A laboratory incubation study was conducted using microlysimeters as described by Nadelhoffer (1990). A factorial arrangement of treatments included three peanut varieties (ANorden, GA 02-C, and NC V-11), three residue types (leaves, stems, and a 1:1 mixture of leaves to stems), and two residue placements (incorporated or surface placed) with four replications.

A Dothan sandy loam 0-2% slope (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) soil was obtained from the Wiregrass Research and Extension Center

(31º21’05”N, 85º20’10”W, 117 m elevation) in Henry County, Alabama on July 10, 2006. The soil sample was obtained from a weed-free, fertilizer-free plot to a depth of 15 cm. The site had not been under cultivation for at least five years prior to sample collection. The sample was sieved to pass a 2 mm sieve and stored at 5 ºC until use in the study. Prior to incubation, field capacity was determined (three replications) using pressure plate methodology (Kosugi et al., 2002) at -12 kPa at a soil bulk density of 1.3 g cm^{-3}. Soil moisture content was determined by drying subsamples in an oven at 105 ºC. Initial soil characteristics are shown in Table 61.

Three peanut varieties, ANorden (runner type), NC V-11 (Virginia type) and GA 02-C (runner type), were grown at the Upper Coastal Plain Experiment station, Edgecombe County, North Carolina (35º56’07”N, 77º46’31”W, 34 m elevation) on a Norfolk loamy sand, 2-6% slope (Fine-loamy, kaolinitic, thermic Typic Kandiudults). The post-harvest residues were separated into leaves and stems, dried at 60 ºC, and ground to pass a 1 mm sieve. Soil samples were hydrated with deionized water to 85% of field capacity and packed into the upper chamber of the microlysimeters at the rate of 50 g of soil on a wet weight basis (42.5 g on a dry weight basis). One hundred mg of each peanut residue type (leaves, stems, and a 1:1 mixture of leaves:stems from each peanut variety) was either incorporated into or placed on the surface of the soil to represent conventional tillage and conservation tillage, respectively. Previous work has shown that peanut has an approximate stem to leaf ratio of 0.59 to 0.41 on a mass basis (Thippayarugs et al., 2008), and the 1:1 ratio served as an approximation of the post-harvest litter ratio. The rate of 100 mg residue per 42.5 g soil on a dry weight basis represented an application rate of 3.88 Mg ha^{-1}. The number of analyses dictated that

microlysimeters be split into two blocks. Microlysimeters were assigned randomly within each block. Each block consisted of 36 microlysimeters plus four control microlysimeters containing soil only. Initial C and N concentrations of stem and leaf tissue from the three peanut varieties are shown in Table 62.

Nitrogen mineralization

Microlysimeters were aerobically incubated in the dark at 25 ºC and retrieved 1, 3, 7, 14, 28, 56, 84, 112, 154, 196, and 252 days after project initiation. Upon retrieval, 100 mL of 0.01 M $CaCl_2$ was added to the upper chamber and allowed to equilibrate with the soil for 30 min (Nadelhoffer, 1990). The soil was leached of the solution by applying a suction of -60 kPa via vacuum pump, maintaining an approximate soil moisture content of 85% of field capacity. The microlysimeters were weighed before and after each extraction and deionized water was periodically added during the study to maintain soil moisture at 85% of field capacity. The extracted solution was analyzed for NH_4-N and NO_3-N concentrations using microplate methodology (Sims et al., 1995). The microplates were read using a µQuant™ microplate spectrophotometer (BioTek Instruments, Inc., Winooski, VT) against prepared standards with a linear coefficient of determination >0.995. Cumulative net N mineralized was calculated as the total net N mineralized divided by the mass of the soil on a dry weight basis. Relative N mineralized was calculated as cumulative net N mineralized divided by the total initial N of the soil and residue (Isaac et al., 2003). Apparent N mineralized was calculated as the total cumulative net N mineralized minus the cumulative net N mineralized from soil divided by the total N of the initial residue (Balkcom et al., 2004; Isaac et al., 2003).

Carbon mineralization

After each extraction, the microlysimeters were purged of CO_2 by pumping CO_2-free air through the system for 3 min before sealing the system (Nadelhoffer, 1990). The microlysimeters were allowed to accumulate CO_2 for 3 hours at room temperature before a 3 mL air sample was collected via syringe and injected into a sealed 3 mL storage vial. Samples were stored at 4 ºC until CO_2 concentrations could be determined using a Varian Star *cx* gas chromatograph (Varian, Walnut Creek, CA) with a 4 m Haysep R column and a ^{63}Ni electron capture detector. A N_2 carrier gas at a flow rate of 17 mL min^{-1} carried the sample to the detector heated to 350 ºC. The percent CO_2 concentration of the sample was converted to mass of C as CO_2 per kg of soil per microlysimeter volume using the ideal gas law. Cumulative C mineralized was calculated by interpolation based on the CO_2-C evolution rate at each sampling time and divided by the soil mass. Carbon turnover was calculated as the total cumulative C mineralized divided by the total initial C of the soil and residue (Balkcom et al., 2004; Isaac et al., 2003). Apparent C mineralized was calculated as the total cumulative C mineralized minus the cumulative C mineralized from soil divided by the total C of the initial residue. Carbon:N mineralization was calculated by dividing the cumulative CO_2-C mineralized at the end of the study by the cumulative N mineralized at the end of the study (Balkcom et al., 2004).

Statistical analysis

Significant effects were identified by analyses of variance as implemented in SAS 9.1.3 using PROC GLIMMIX procedures (SAS, 2003). Repeated measures were modeled within PROC GLIMMIX models using the RANDOM _REPEATED_ option (SAS, 2006). Pairwise comparisons of treatment means were identified using the SLICEDIFF option with an LSMEANS statement within PROC GLIMMIX. Effects were considered significant at $p < 0.05$. Means and standard errors of significant effects of the reduced models were obtained using PROC MEANS.

Results and Discussion

Carbon mineralization

Carbon mineralization rates did not differ among varieties or peanut plant parts during this study ($p=0.2684$ and 0.4152, respectively; Table 63), although they were higher when compared to the soil-only control ($p<0.0001$ and $p=0.0007$, respectively; Figure 24). Placement was not a significant variable for cumulative C mineralization ($p=0.9930$, Table 63). The lack of difference owing to placement is in general agreement with field results described in Chapter IV of this volume (Table 47), which showed there were no placement differences for C loss from ANorden and GA 02-C on a Dothan sandy loam, although there were placement differences for NC V-11 under field decomposition. Microlysimeters may have limited applicability for the study of tillage differences because the incubation environment under laboratory conditions is likely to have higher O_2 concentrations than those found under field conditions, thereby stimulating greater aerobic microbial activity, while field CO_2 concentrations are several hundred times

higher than those found in the atmosphere (Brady and Weil, 2002). Indeed, the work establishing microlysimeter incubations noted that O_2 depletion was not inhibitory for microbial respiration (Nadelhoffer, 1990). Since aerobic decomposition is faster than anaerobic decomposition (Brady and Weil, 2002), aerobic incubation in microlysimeters may be expected to exhibit higher microbial respiration rates than those found under field conditions, particularly as the chronosequence progresses away from a tillage operation.

Figure 24 shows the cumulative CO_2-C mineralized over the course of the experiment per kg of soil. The figure shows that 252 d after residue application, C mineralization continued to increase, even in relation to the control. There is some evidence, however, that C mineralization may have begun to plateau at that time, judging by the slope and curvature of the lines in Figure 24, particularly with respect to the no-residue control, though further studies should be conducted to better determine the time required to reach a steady state of C mineralization from peanut residue. Previous studies have shown that C mineralization from peanut residue did not plateau after 98 d on Tifton and Greenville soils (Balkcom et al., 2004). That study showed approximately 1100 mg CO_2-C kg^{-1} soil was mineralized after 98 d, while our study mineralized approximately 700 mg CO_2-C kg^{-1} soil over the same period, although residue-loading rates were somewhat higher in the 2004 study (4.5 Mg ha^{-1} compared to 3.9 Mg ha^{-1} in our study). After 252 d of incubation, approximately 1300 – 1800 mg CO_2-C kg^{-1} soil was mineralized from soil plus peanut residue, compared to approximately 800 mg CO_2-C kg^{-1} soil from the soil-only control (Table 64). Although pairwise comparisons of plant parts were not significantly different for any variety or placement after 252 d of incubation (data not shown), stems generally mineralized more C than leaves because

stems had a higher C:N ratio than leaves (Table 62), and therefore C was not limiting to microbial metabolism. Likewise, C turnover was generally higher for stems than for leaves after 252 d (Table 64), although all pairwise comparisons of main effects were not significantly different (data not shown). Our results are in agreement with Jin et al. (2008), who showed similar C mineralization rates between peanut stems and leaves during a 12 week incubation with Chinese loess soil. On the other hand, faster decomposition of peanut leaves compared to stems has been reported on a northeastern Thai soil (Thippayarugs et al., 2008).

Since the C:N ratio of stems was >30 for all varieties (Table 62), the high rate of stem C mineralization is likely due to the relatively lower C:N ratio of the soil (20.6; Table 61). In effect, soil N immobilization offset the high C:N ratio of peanut stems thereby facilitating C mineralization from stems. The values for total C:N mineralized at the end of the experiment were generally somewhat high when the residue substrate contained stems (Table 64), evidence that N was somewhat limiting for decomposition in this study (Wood and Edwards, 1992). When the substrate contained leaves only, however, the C:N mineralized at the end of the experiment was lower, generally below 20, indicating that net N was not immobilized under those conditions. Soil-only controls had a C:N mineralized ratio of 13.6 at the end of the study (Table 64), indicating that C was limiting without the addition of substrates.

The total C turnover after 252 d was in the range of 11-15% (Table 64), which was low compared to that reported by Balkcom, et al. (2004), who found that peanut residue C turnover after 98 d ranged from 17-19% in Tifton and Greenville soils. The discrepancy may be due to the higher rates of residue loading than were used in the

present study, attributable to the priming effect (Fontaine et al., 2004), and/or may be due to the soil type itself, i.e., the Dothan soil used in the present study had a lower pH and C:N ratio than the Tifton and Greenville soils. At least some of the apparent C mineralized is likely due to the priming effect, particularly in cases where the average apparent C mineralized is >100% (Table 64).

Nitrogen mineralization

Table 65 shows placement differences were not significant for the cumulative net N mineralization of peanut residue (p=0.66). This result supports that found in Chapter IV of this work, where rates of N loss were similar among tillage systems for all three varieties on a Dothan sandy loam (Table 55). The result also agrees with with previous incubation studies involving surface-placed versus incorporated peanut residue (Smith and Sharpley, 1990).

There were significant differences between plant parts for the cumulative net N mineralization from peanut residue (p=0.0002; Table 65). This is because leaves and stems mineralized net N at different rates for the varieties GA 02-C and ANorden (p=0.0179 and 0.0085, respectively; Table 66), although net N mineralization of leaves and stems from the variety NC V-11 were not considered significantly different (p=0.0736; Table 66).

Pairwise comparisons of varieties for each plant part showed that net N mineralization rates were not significantly different from each other, nor were they significantly different than the control (data not shown), though net N mineralization from peanut leaf litter was greater than the control after 50 d (Figure 25). The lack of

significant differences for net N mineralization between peanut residues and the soil-only control suggests that N mineralization from peanut residue was negligible. Since N mineralization from amended soils and the soil-only control were equal, N credits to subsequent crops were not supported from these data. Leaf litter contained a higher N concentration than stems (Table 62) and therefore had a greater net N mineralization rate compared to the soil-only control, although not statistically significant. Initial leaf residue C:N ratios were <19, and therefore would be expected to mineralize net N (Brady and Weil, 2002). By the same reasoning, the high initial C:N ratios of stems (>30) should be expected to immobilize net N. Although net N immobilization from stems was not significantly different from the soil-only control, close inspection of the data in Figure 25 shows that the control exhibited slightly higher net N mineralization rates compared to those from stems of any of the varieties in the first 50 d. The suppression of net N mineralization by stems during the initial period of incubation suggests net N immobilization during that time.

At the end of the experiment, C:N mineralized was higher from stems than from leaves (Table 64), suggesting an N limitation under stem decomposition (Balkcom et al., 2004). Similarly, the relative N mineralization during stem decomposition tended to be lower than for leaves and on par with that from the soil-only control. Additionally, the apparent N mineralized from stems was generally lower than that from leaves, and in some cases generated negative values (Table 64), further indicating net N immobilization during stem decomposition. Mixing stems and leaves resulted in generally higher C:N mineralized than leaves only (Table 64), suggesting that mixing residues of varying litter quality enhances C mineralization. Increasing the total N pool and decreasing the initial

C:N ratio by addition of peanut leaves to stems partially explains greater C mineralization by the mixture, but it is interesting to note that C:N mineralized by the mixture was on par with that observed by stems only. It may be that a variety of substrates provided greater micro-environmental niches, limited competition among microbial communities by diversifying the organic C profile, and therefore mineralized more C for the same amount of N than if there were only one substrate type present (Fontaine et al., 2004).

Relative N mineralization of the Dothan soil-only control was approximately 11% after 252 d (Table 64). This compares to 10% relative N mineralized from soil only after 84 d of aerobic incubation at 35 ºC (10 ºC higher than our study) found by Smith and Sharpley (1990). It has been estimated that only 1-3% of soil organic N is mineralized annually under field conditions (Bremner, 1965). The higher rate of relative N mineralization under laboratory incubation studies compared to those expected under field conditions is probably due to the increased O_2 supply under laboratory conditions as previously discussed, though elevated temperatures of incubation compared to soil temperatures in the field would also have the effect of increasing microbial activity.

Conclusions

No differences in C mineralization nor net N mineralization were found between surface placed and incorporated peanut residues on a Dothan sandy loam after 252 days. Addition of peanut residue increased C mineralization rates but not net N mineralization rates compared to a soil-only control due to soil N limitations. Peanut stems and a 1:1 mixture of leaves and stems did not have greater net N mineralization rates compared to the control, while peanut leaves mineralized net N compared to the soil-only control.

Peanut variety was not a significant variable during C mineralization or net N mineralization in this study. Net N mineralization did not appear sufficient to warrant N credits to succeeding crops. Similar conclusions have been reached by other researchers studying peanut residue decomposition in the southeastern US (Balkcom et al., 2004; Meso et al., 2007), although these conclusions may not apply on soils in other parts of the world (Jin et al., 2008).

Table 61. Initial soil characteristics of a Dothan soil collected from the Wiregrass Research and Extension Center in Henry County, Alabama.

Parameter	
Field capacity (%)	11.7
C (g kg^{-1} soil)	11.1
N (g kg^{-1} soil)	0.54
C:N ratio	20.6
pH	5.90

Table 62. Initial C and N concentrations of leaves and stems from three peanut varieties.

Variety	Part	N (g kg^{-1})	C (g kg^{-1})	C:N
GA 02-C	Leaves	23.8	407.2	17.1
	Stems	13.5	407.5	30.1
NC V-11	Leaves	21.7	403.6	18.6
	Stems	12.6	414.3	33.0
ANordane	Leaves	22.2	408.0	18.4
	Stems	11.9	405.1	34.0

Table 63. Analysis of variance for fixed effects and interactions of cumulative C mineralization per mass of soil.

Effect	P>F
Placement	0.9930
Variety	0.2684
Variety x Placement	0.6051
Part	0.4152
Part x Placement	0.8433
Variety x Part	0.7366
Variety x Part x Placement	0.7389

Table 64. Cumulative C and net N mineralized, cumulative C turnover, relative N mineralized, relative residue N mineralized, and C:N mineralized after 252 d of incubation from parts of three peanut varieties at two placements. Values represent the means ± standard errors.

Variety	Part	Placement	Cumulative C mineralized (mg kg^{-1} soil)	Cumulative N mineralized (mg kg^{-1} soil)	Cumulative C turnover (%)	Relative N mineralized (%)	Apparent C mineralized (%)	Apparent N mineralized (%)	C:N mineralized
ANorden	Leaves	Buried	1485.8 ± 278.8	75.6 ± 4.7	12.3 ± 2.3	12.8 ± 0.8	67.7 ± 40.9	25.1 ± 13.0	23.6 ± 2.6
		Surface	1481.2 ± 174.7	72.4 ± 2.3	12.3 ± 1.4	12.2 ± 0.4	51.9 ± 14.3	25.9 ± 11.3	20.3 ± 2.9
	Mix	Buried	1342.0 ± 187.4	63.7 ± 3.2	11.1 ± 1.6	11.0 ± 0.5	52.9 ± 36.6	7.5 ± 14.5	21.4 ± 3.7
		Surface	1801.6 ± 382.7	53.2 ± 15.6	14.9 ± 3.2	9.2 ± 2.7	100.9 ± 54.7	-14.2 ± 36.8	37.3 ± 17.0
	Stems	Buried	1659.7 ± 239.0	58.8 ± 2.2	13.7 ± 2.0	10.4 ± 0.4	101.8 ± 32.5	-25.9 ± 7.9	29.1 ± 5.0
		Surface	1579.8 ± 99.8	61.6 ± 4.3	13.1 ± 0.8	10.8 ± 0.8	78.0 ± 19.7	3.4 ± 34.9	26.7 ± 4.3
GA 02-C	Leaves	Buried	1271.4 ± 160.9	74.1 ± 2.3	10.5 ± 1.3	12.4 ± 0.4	60.7 ± 31.7	19.1 ± 7.7	17.4 ± 2.6
		Surface	1404.8 ± 163.7	71.6 ± 4.6	11.6 ± 1.4	12.0 ± 0.8	59.3 ± 13.0	19.4 ± 11.0	19.5 ± 1.5
	Mix	Buried	1650.6 ± 196.5	62.7 ± 2.7	13.7 ± 1.6	10.7 ± 0.5	85.0 ± 21.8	4.6 ± 11.8	26.3 ± 3.0
		Surface	1731.7 ± 292.0	67.9 ± 4.5	14.3 ± 2.4	11.6 ± 0.8	103.6 ± 49.2	16.5 ± 17.1	27.7 ± 6.3
	Stems	Buried	1546.2 ± 237.2	66.7 ± 1.6	12.8 ± 2.0	11.7 ± 0.3	58.7 ± 23.6	24.6 ± 7.0	25.4 ± 4.3
		Surface	1555.3 ± 212.3	59.3 ± 3.8	12.9 ± 1.8	10.4 ± 0.7	75.0 ± 39.2	-4.4 ± 21.4	27.2 ± 5.1
NC V-11	Leaves	Buried	1317.3 ± 83.6	73.7 ± 4.5	10.9 ± 0.7	12.5 ± 0.8	50.6 ± 26.4	25.5 ± 12.8	18.2 ± 1.9
		Surface	1401.4 ± 186.0	75.8 ± 1.2	11.6 ± 1.5	12.8 ± 0.2	59.5 ± 32.2	29.7 ± 13.0	17.1 ± 5.7
	Mix	Buried	1444.4 ± 248.6	65.4 ± 0.6	11.9 ± 2.1	11.3 ± 0.1	63.2 ± 37.0	16.3 ± 7.5	23.8 ± 4.4
		Surface	1412.2 ± 153.1	70.1 ± 2.5	11.7 ± 1.3	12.1 ± 0.4	49.7 ± 27.2	28.0 ± 12.3	20.0 ± 1.6
	Stems	Buried	1551.8 ± 216.7	62.0 ± 1.0	12.8 ± 1.8	10.9 ± 0.2	103.5 ± 22.2	-13.7 ± 3.4	21.8 ± 2.1
		Surface	1398.5 ± 54.9	61.9 ± 1.3	11.6 ± 0.5	10.9 ± 0.2	42.6 ± 20.4	13.5 ± 7.5	22.6 ± 0.6
	Control		794.5 ± 149.1	60.7 ± 2.7	7.1 ± 1.3	11.2 ± 0.5	n/a	n/a	13.6 ± 3.0

Table 65. Analysis of variance for fixed effects and interactions of cumulative net N mineralization per mass of soil.

Effect	P > F
Placement	0.6600
Variety	0.0819
Variety x Placement	0.4058
Part	0.0002
Part x Placement	0.6415
Variety x Part	0.9326
Variety x Part x Placement	0.9264

Table 66. Analysis of variance for pairwise comparisons of peanut plant parts by peanut variety for cumulative net N mineralization per mass of soil.

Variety	Part comparison		P > F
ANorden	Leaves	Mix	0.1047
ANorden	Leaves	Stems	0.0085
ANorden	Mix	Stems	0.2537
GA 02-C	Leaves	Mix	0.0229
GA 02-C	Leaves	Stems	0.0179
GA 02-C	Mix	Stems	0.8709
NC V-11	Leaves	Mix	0.1758
NC V-11	Leaves	Stems	0.0736
NC V-11	Mix	Stems	0.6934

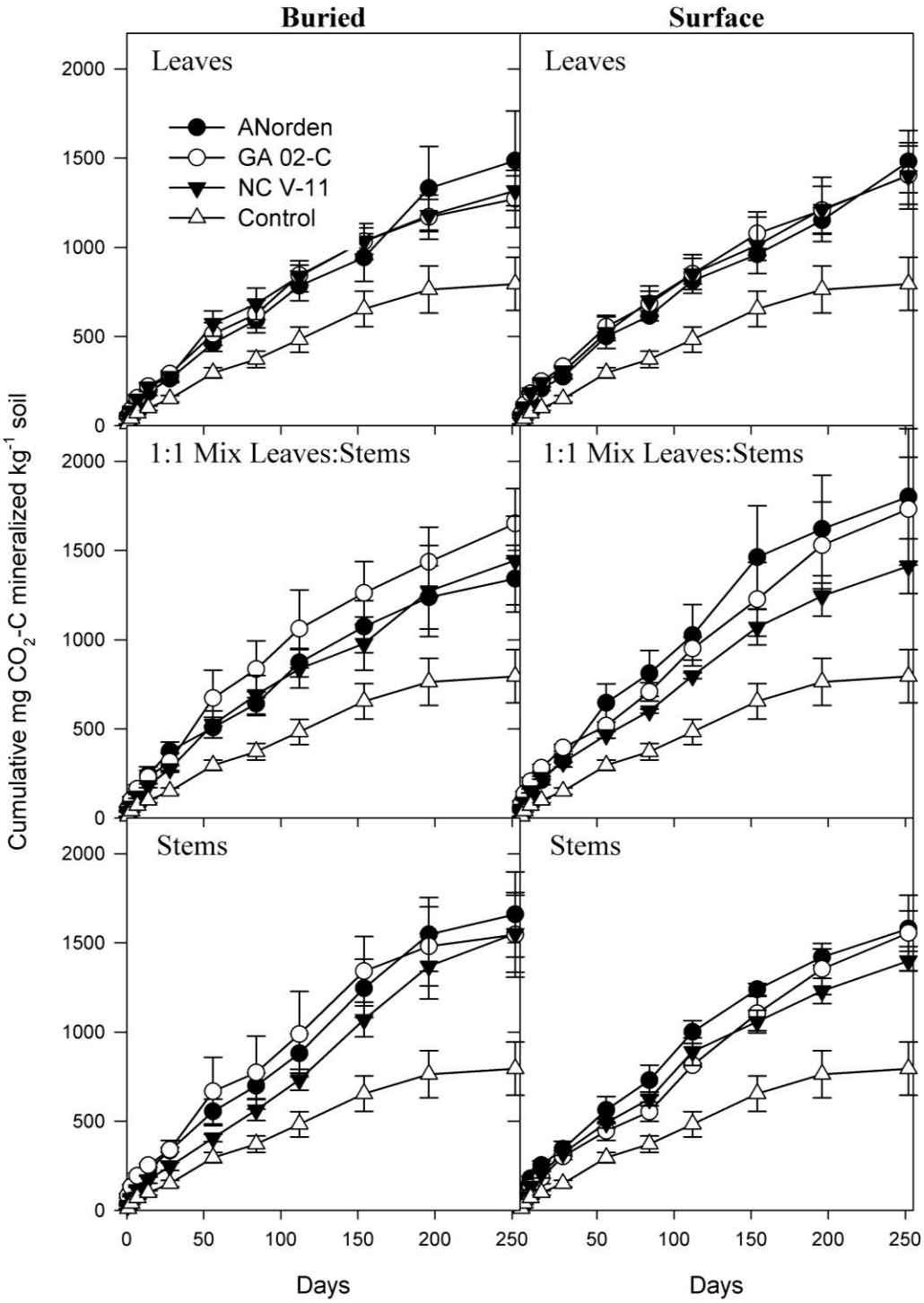

Figure 24. Cumulative C as CO_2 mineralized from 100 mg peanut residue per kg of Dothan soil over time. Error bars represent standard errors of the mean.

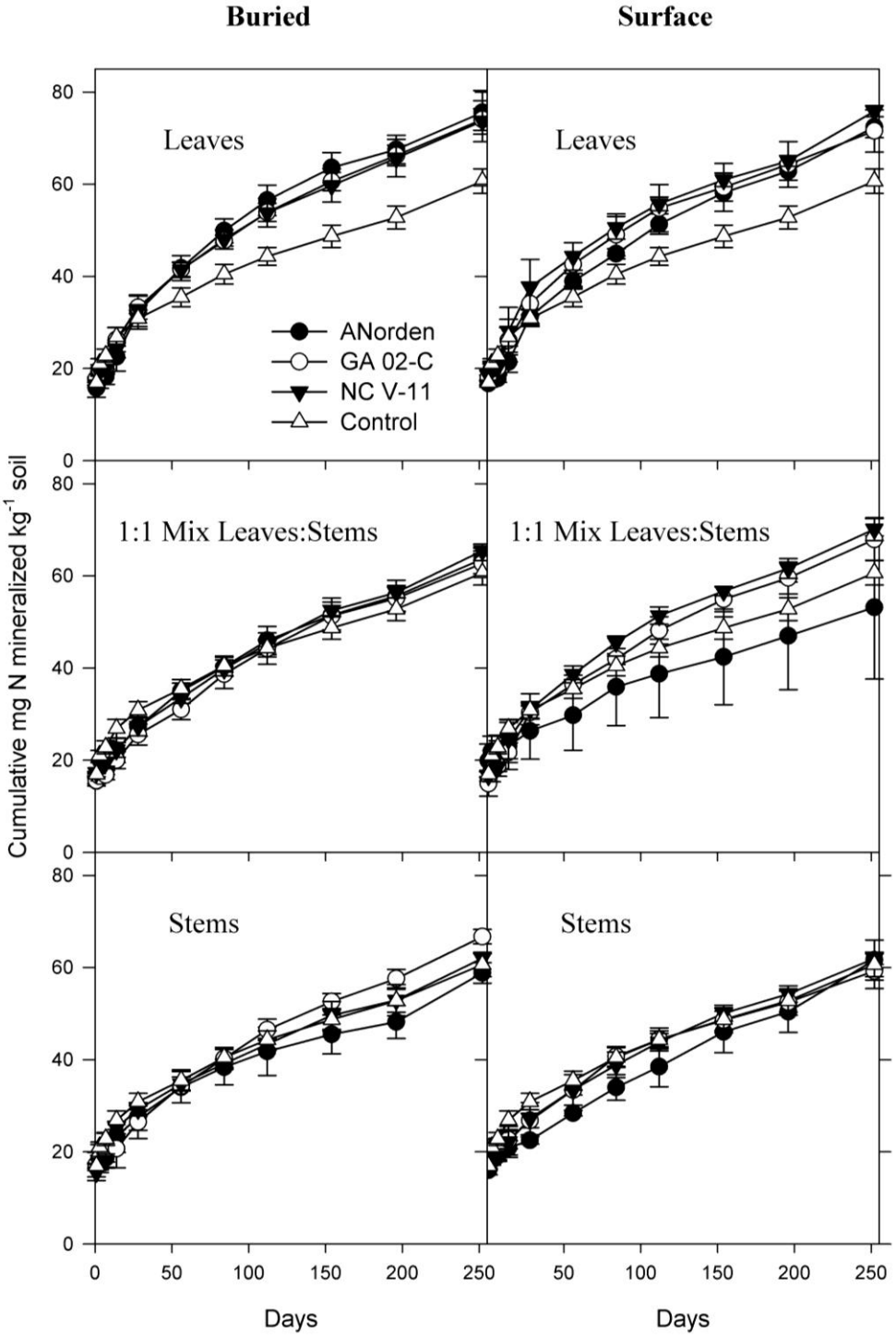

Figure 25. Cumulative net N mineralized from 100 mg peanut residue per kg of Dothan soil over time. Error bars represent standard errors of the mean.

VI. Conclusions

Although there is increasing interest regarding the adoption of conservation tillage systems among vegetable producers, significant challenges remain before widespread adoption will occur. One of the largest obstacles is adequate suppression of weeds. The system outlined in this work has shown that it is possible to obtain collard yields typical for the region while simultaneously employing no-till, sequestering C, and achieving adequate weed control without the use of herbicides during collard production. There may be some benefit to the use of invasive perennial leguminous species as organic mulching material in that:

1. They can often be found on the farm and controlled in a productive manner by utilizing them as mulches.
2. They may offer a balance between mulch persistence and a high N contribution to subsequent crops.
3. They may increase SOC in surface horizons when left on the soil surface.

These data show that mass, C, and N loss are much more rapid during the initial labile phase of decomposition when residues are buried compared to surface placed. However, the decomposition rates of the recalcitrant portions of the residues are generally the same regardless of residue placement, with the notable exception of straw. This system of vegetable production can improve soil quality while keeping land

agriculturally productive, and may interest limited input producers who are breaking new ground or wish to improve depleted soils.

An appendix to the dissertation contains weed suppression data from various organic mulches and forage soybean as a summer cover crop in manuscript format. Perennial leguminous species used as cut-and-carry mulches may not be as effective as straw for weed control because they do not provide as thick a cover, and therefore allow more light transmittance to the soil surface, allowing more weed seed germination. However, this study showed that collard yields were equal for all treatments, suggesting that the differences in weed control were not great enough to limit yields. Three years after initiation of no-till, grass, sedge, and broadleaf weeds were under reasonable control and SOM increased to approximately 3.4% at the 0-5 cm depth, an increase of approximately 2.0% over three years. Broadleaf weed control was significantly enhanced by the application of organic mulches during the first year. During the second year, the weed population shift toward grasses was also mitigated by mulch application. No-till showed high levels of broadleaf and sedge weed coverage during the first year of conversion, but it appears that no-till practices shift away from those populations in subsequent years.

The second half of this work addressed the question of N credits to crops following peanut. Although there is a growing body of literature to show that N credits are not warranted to subsequent crops after peanut, there is still some confusion among producers and extension personnel alike regarding N credits following peanut. These data presented in this work show that N was released too quickly from peanut residues to warrant N credits following peanut, regardless of residue placement (surface or buried),

location (North Carolina or Alabama), and variety. Furthermore, these data showed that net N mineralization from peanut residues was not greater than soil-only controls under laboratory conditions, further evidence that N from peanut residues may not become plant available in significant quantities within a reasonable amount of time.

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Appendicies

Appendix 1: Cover Crop Residue and Organic Mulches Provide Herbicide-Free Weed Control during No-Till Collard Production

Abstract. Limited input producers may adopt no-till if sufficient weed suppression can be achieved. High-biomass producing cover crops used in conjunction with organic mulches may provide sufficient weed control in no-till vegetable production. Our objective was to quantify weed suppression from a summer cover crop and organic mulches under no-till collard production. Forage soybean residue did not suppress weeds, but mulches were generally effective. Weed populations shifted away from broadleaves and sedges, but reasonable grass control was not achieved until three years after conversion to no-till. Grass suppression was greater when mulches were applied after the first year. Collard yield was not affected by any cover crop or mulch treatment.

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INTRODUCTION.

Systems involving conservation tillage with cover crops, mulch, and rotations have been identified as a soil management system with potential to improve food security for millions of hungry people, as well as contribute to political stability, global peace and the success of civilization (Lal, 2008). However, adequate weed suppression in conservation tillage systems remains problematic without herbicides. Reduced herbicide weed management in conjunction with high-biomass producing cover crops and organic mulches may maintain weeds at manageable levels while simultaneously improving soil quality.

Weed control in conservation tillage systems usually depends on herbicides, so producers interested in growing herbicide-free vegetables are generally excluded from adopting conservation tillage. However, there is a growing body of literature devoted to the establishment of conservation tillage, often utilizing high-biomass cover crops, as a feasible technology for herbicide-free olericulture. Used in conjunction with organic mulches, sufficient weed control in conservation tillage vegetable production may be achieved.

Conservation tillage

Conservation tillage is defined as agricultural production that leaves at least 30% residue on the soil surface after planting, and may include no-till, ridge till, mulch-till, and strip-till (Uri, 1999). Conservation tillage is known to reduce soil erosion and increase soil organic matter (SOM) content. Associated benefits, such as limiting phosphorus (P) runoff and improving soil infiltration (Uri, 1999), soil structure and aggregate stability (Riley et al., 2008), etc., are beneficial to producers and the environment alike. Other benefits of conservation tillage include reduced energy and

labor costs (Siemans and Doster, 1992) and increased soil moisture retention (Li et al., 2008). Disadvantages of conservation tillage may include reduced weed control, delayed planting dates due to lower soil temperatures in spring, and equipment costs (Gupta et al., 1988; Rutledge, 1999). Agricultural production in the USA has seen a marked increase in adoption of conservation tillage in recent decades. Between 1998 and 2005, no-till corn (*Zea mays*) acreage in the US increased from 9.2 million to 18.6 million acres, while conventionally tilled corn acreage decreased from 24.5 million to 20.6 million acres over the same period (USDA, 2008c).

Among vegetable producers, there is a perceived increase in insect, disease and weed pressure with the adoption of conservation tillage. Although no data is available for conservation tillage adoption among vegetable producers, it is likely that vegetable producers may be willing to adopt conservation tillage if sufficient pest management can be achieved. Vegetable producers interested in adopting herbicide-free conservation tillage may include organic producers, farmers participating in community supported agriculture (CSA) programs, and direct market producers because of the public interest in obtaining local herbicide-free produce. Conventional vegetable producers should be able to adopt conservation tillage easier than organic producers because they can rely on herbicides and chemical fertilizers. However, much of the research conducted on herbicide-free weed control in conservation tillage olericulture has centered on organic production since it relies on increased SOM for fertility (provided by increased residue on the soil surface) and cannot use chemical herbicides available to conventional growers.

Conventional tillage tends to shift weed populations toward both annual and perennial grasses, while conventional tillage tends to shift populations toward broadleaved weeds (El Titi, 2003; Teasdale et al., 1991). Under conservation tillage, germination and emergence of small, old, and deep weed seeds can be retarded (Bond and Grundy, 2001; El Titi, 2003), which may shift weed populations in favor of those with high seed production rates such as grasses (El Titi, 2003) or those with rhizomes (Torresen et al., 2003). Additional perennial grass control may be obtained mechanically by cutting before seeds become viable (Peigne et al., 2007).

The goal of herbicide-free vegetable production is to maintain weed populations at manageable levels, not to eliminate weeds altogether (Bond and Grundy, 2001), though weed control is vital to maintain pressures below yield reducing threshold levels. Traditionally, organic vegetable producers utilize cultivation or hand weeding for weed control, though feasible methods of weed control in organic conservation tillage systems include hand-weeding, brush weeding, mowing, cutting, flaming (Bond and Grundy, 2001; Peigne et al., 2007), and the use of plastic, fabric or organic mulches (Feldman et al., 2000).

Cover crops

The use of cover crops during fallow periods can suppress weeds via rapid growth, providing a thick ground cover after termination (Nelson et al., 1991), competing with weeds during growth, and releasing allelopathic compounds during residue decomposition (Grundy et al., 1999). Termination of cover crops without the use of herbicides can be as effective as chemical termination using mechanical crimp and roll methods after the soft dough stage of grain development (Ashford and Reeves, 2003).

The killed residue acts as a mulch, thereby suppressing weeds by reducing light transmittance and soil temperature amplitude (Teasdale and Mohler, 1993). During organic sweet potato (*Ipomoea batatas* (L.) Lam.) production in North Carolina, Treadwell et al. (2007) found that a cover crop mixture of rye and hairy vetch with reduced tillage was as effective as tillage for the suppression of dicot weeds but not monocot weeds, although conservation tillage suppressed yields by at least 45% owing to the increase in monocot weeds.

Mulches

Mulching may include living mulches, plastic, paper, or loose organic materials. Living mulches are mainly used for perennial crop production (Ingels et al., 1994), and require careful selection and management in order to limit competition with the main crop (Costello and Altieri, 1994). Woven polypropylene mulches are also usually used for persistent weed control in perennial crops (Bond and Grundy, 2001). Polyethylene plastic mulches are widely used for both conventional and organic vegetable production, but cleanup and disposal are problematic. Paper mulches have been shown to suppress weeds in transplanted vegetable production, with control similar to that of black plastic (Runham and Town, 1995). Most annual and some perennial weeds were suppressed using 0.8-1.4 t ha^{-1} of shredded newspaper during sweet corn, soybean, and tomato production (Munn, 1992). Paper mulches are biodegradable, thereby eliminating the labor and cost associated with plastic mulch removal while improving environmental sustainability.

The same attributes may also apply to loose organic mulches. The quantity needed to suppress weeds may make them cost prohibitive if they are purchased and

transported to the production area, but may be economically feasible if they are produced *in situ* (Merwin et al., 1995). Cut ryegrass (*Lolium* spp.) as mulch is more economical than cultivation for weed control during tomato and pepper production (Edwards et al., 1995). It is important to ensure that straw does not contain seeds in order to circumvent volunteer infestation (Yordanova and Shaban, 2007).

Decomposition of the organic mulch residue may have allelopathic effects on weeds as well as on the cash crop by releasing natural phytotoxins (Wallace and Bellinder, 1992). Russo *et al.* (Russo and Kindiger, 2007) found that mulching with fresh kenaf (*Hibiscus cannabinus* L.) chips reduced cabbage (*Brassica oleracea* L.) yield but did not affect onion (*Allium cepa* L.) yield, a phenomenon possibly attributed to allelopathy of the fresh mulch. The same study showed similar weed control between black plastic mulch and kenaf chips.

Decomposition of carbon (C) rich mulches such as straw may result in reduced nitrogen (N) availability as the soil microbial community temporarily immobilizes ammonium and nitrate in competition with plants. The use of N rich mulches may circumvent this problem by lowering the C:N ratio, though residue with higher N contents tends to decompose faster. Therefore, it is desirable to strike a balance between mulch N content and mulch persistence. On the other hand, C rich mulches can reduce nitrate leaching after harvest via immobilization (Doring et al., 2005).

During echinacea (*Echinacea purpurea* Moench. [L.]) production in Australia, hay mulch exhibited >90% greater weed control compared to a non-weeded control and was comparable to hand-weeding (Kristiansen et al., 2008). The same experiment showed 85% weed control by hay mulch for lettuce production, compared with 96%

control by hand-weeding and 66% by tillage. Straw mulch treatments 10 cm thick exhibited 2.0% weed coverage 38 days after transplanting Chinese cabbage (*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt) in the UK, compared to 0.2% for hand-weeding, 0.8% for black polyethylene, and 76.3% for a non-weeded control (Runham and Town, 1995). Yordanova and Shaban (2007) showed that wheat straw mulch suppressed dicotyledonous weeds more effectively than monocotyledonous, but did not suppress perennial weeds during broccoli (*Brassica oleracea* L. var. *italica* Plenck)production. The authors also noted that it is important to ensure that straw mulch does not contain seeds in order to prevent volunteer weed infestation.

There is evidence that mulching several weeks after transplanting can improve weed suppression mainly by improving mulch persistence later into the growing season (Law et al., 2006), but mulch application should be done with care to prevent lodging of the crop (Boyhan et al., 2006) and shading of prostrate crop growth (Pedreros et al., 2008). Inhibition of light transmittance appears to be the greatest factor for weed suppression by mulches (Steinmaus et al., 2008).

More research is needed before limited-input producers are able to widely adopt conservation tillage. Creative approaches to achieve adequate weed control may include the use of high-biomass winter cover crops, followed by high-biomass summer cover crops for fall vegetable production. Such a system provides all the advantages of limiting weed emergence by supplying the thickest mat of residue possible. Additional late season weed suppression may be achieved by the application of organic mulches after crop establishment. Ideally, those mulches may be produced on the farm in order to limit purchase and transport costs, and may even utilize invasive or weedy perennial

leguminous species, such as mimosa (*Albizia julibrissin* Durazz.) or lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don) cuttings, as long as those mulches are applied before seeds become viable. If summer and winter cover crops, as well as organic mulches, are chosen carefully with regard to persistence and nutrient content, it seems possible to keep land agriculturally productive while simultaneously improving soil quality.

The objective of this experiment was to quantify weed suppression effects of a summer cover crop and organic mulches under no-till collard (*Brassica oleracea* L. Acepahala group cv. Champion) production during the first three years of conversion from conservation tillage. This data should enable vegetable producers to make more informed decisions regarding residue management, including the adoption of conservation tillage.

MATERIALS AND METHODS

Studies were conducted at the E.V. Smith Research Center Plant Breeding Unit in South Tallassee, AL (N 32º29.29' W85º53.26, 66 m elevation) between 2005 and 2008 on a Wickham fine sandy loam soil, 0-2% slopes (Wickham fine-loamy, mixed, semiactive, thermic Typic Hapludults). The experiment was a 2 (summer cover crops) by 4 (organic mulches) factorial randomized complete block design replicated four times. Each block was 24.4 m long and 9.1 m wide, with experimental units measuring 9.1 m long and 3.0 m wide. Two main treatments consisted of a Derry forage soybean (*Glycine max* (L.) Merr. cv. Derry, group VI) summer cover crop and a no summer cover crop control. Four sub-treatments consisted of *in situ* organic mulches: mimosa prunings ≤1

cm in diameter, lespedeza (*Lespedeza cuneata* cv. AU Grazer) cuttings, wheat straw (*Triticum aestivum* L.), and a no-mulch control.

The plots were disk harrowed at the initiation of the experiment in October 2005, then limed and fertilized according to soil test recommendations. Each year, a winter cover of rye (*Secale cereale* L. cv. Elbon) was mechanically terminated using a roller-crimper (Ashford and Reeves, 2003) or chemically terminated if an adequate kill was not obtained in late April. Two weeks after termination, summer cover crop treatments were planted using inoculated Derry forage soybean at 112 kg ha^{-1} on 19 cm rows using a Marliss no-till drill. In mid to late August, summer cover crops were mechanically terminated using a roller-crimper or chemically terminated if an adequate kill was not obtained. Two weeks after summer cover crop termination, rows were cleared using row cleaners on a Kinze no-till planter and collards (cv. Champion) seedlings were transplanted 43 cm apart using a single row RJV 600 no-till transplanter (R J Equipment, Ontario Canada) on 76 cm rows. No subsoiling shank was used at any point during the experiment. Mulches were applied at a rate of 6.7 Mg ha^{-1} (oven-dry basis) 21 days after transplanting. Collards were fertilized at a rate of 202 kg N ha^{-1} in three split applications and irrigated using a traveling gun as needed. Hand harvest operations were conducted 65-69 d after transplanting, followed by planting a winter cover crop of rye at a rate of 101 kg seed ha^{-1} on 19 cm rows. Weed coverage was determined using line-transect methodology by counting 50 points along a marked line twice per plot per sampling period. Weeds were classified as broadleaves, grasses or sedges. Twice during 2008, weeds were identified to the species level.

Significant effects were identified by analyses of variance as implemented in SAS 9.1.3 using PROC GLIMMIX procedures and maintaining blocks as a random effect (SAS, 2003). Reduced models were obtained via backward elimination for variable selection using $P > 0.15$ as the criteria for elimination from the model. Inflated Type I error rates associated with the covariance structure in the model was limited by adjusting the denominator degrees of freedom using Kenward-Roger correction in the MODEL statement (Littell et al., 2002). Means and standard errors of significant effects of the reduced models were obtained using PROC MEANS.

RESULTS AND DISCUSSION

Mulching provided weed suppression of broadleaves, grasses and sedges, but forage soybean as a summer cover crop did not (Table A1), likely due to the fact that soybean residue decomposes too quickly to have a lasting mulching effect. In all cases, days after mulching (DAM) were highly significant within each year of the study ($P < 0.0001$). A time by mulch interaction within each year (DAM*Mulch(Year)) was due to both the effect of mulch application and the growth of weeds as the season progressed. Evidence of a mulch by year interaction suggested that weed populations were affected by mulching for three consecutive years. This effect was most apparent on broadleaf control (Figure A1). Mulching the first year was effective for suppression of broadleaf weeds. Suppression of broadleaf weeds during the first year appears to lessen broadleaf infestation during subsequent years, although mulching during 2007-8 did not have the same level of suppression compared to the non-mulched control. Since conservation tillage tends to shift weed populations away from broadleaves (El Titi, 2003; Teasdale et

al., 1991), it is not surprising that broadleaf control can be enhanced with mulch application.

[Table A1.]

[Figure A1.]

The population shift toward grasses under conservation tillage makes grass control more difficult (El Titi, 2003). During the first year of no-till, grass control was not effective using any of the mulches (Figure A2), but subsequent years showed much better grass suppression using mulches compared to the non-mulched control. Grass infestation was maintained below 10% by the application of any mulching material in 2007 (compared to 17% for the non-mulched control), and below 6% in 2008. These data show that mulching suppresses monocot weed populations in no-till systems if used for more than one year compared to the control, and may suggest that >2 years of no-till with high-biomass producing cover crops may be effective at reducing grassy weeds, although more data are needed to support this claim. In any case, the data show that grass populations under no-till are highly variable, with populations increasing dramatically during the second year of conversion from conventional tillage, but decreasing in the third year. Mowing grasses before seed heads become viable may reduce the grass populations to manageable levels during transition to conservation tillage.

[Figure A2.]

During the first year of transition from conventional to conservation tillage, yellow nutsedge (*Cyperus esculentus* L.) control was highly problematic, with total coverage ranging from 7-21% (Figure A3). However, subsequent years of high residue no-till improved sedge suppression, generally below 5% coverage, although there was not much difference between any of the mulching treatments and the control. Bangarwa, *et al.* (2008) showed that straw mulch applied at 7300 kg ha^{-1} (7 cm thick) was effective at reducing medium (0.26-0.50 g) purple nutsedge (*Cyperus rotundus* L.) tuber density, but did not reduce large (>0.50 g) or small (0.10-0.25 g) tuber density for bell pepper production in Clemson, SC. They also found generally comparable tuber density when tilled plots were either straw-mulched at transplanting or hand-weeded every 1-2 weeks. It is interesting to note that sedge coverage was subject to a significant cover crop by mulch interaction (Table A1), resulting from increased sedge suppression by mimosa prunings after a forage soybean summer cover crop in 2006 and increased sedge suppression achieved in control plots when combined with forage soybean in 2007 and 2008 (Figure A3). Although it is unclear why this should be the case, it is apparent that sedge suppression is improved during subsequent years of high-biomass producing cover crops in combination with no-till, with or without the application of mulches. Yellow nutsedge was the only perennial weed species present after three years (Figure A4).

[Figure A3.]

[Figure A4.]

Figure A4 shows the weed infestation 6 d before and 15 d after mulching in 2008 by species averaged over all plots, giving an overall picture of the weeds present three years after initiation of no-till. No individual weed species covers more than 4% of the surface 15 days after mulching, or five weeks after transplanting. This suppression should give the main crop an adequate start to compete successfully with weeds later in the season. Yellow nutsedge was the single major species present at that time, followed by large crabgrass. After three years of high-biomass no-till, the only grasses present were large crabgrass and winter rye, the latter due to viable seed germination from the previous winter cover crop. This underscores the importance of ensuring termination of cover crops and mulches before seeds become viable. Summer annual broadleaves consisted of spiny pigweed (*Amaranthus spinosus* L.), common purslane (*Portulaca oleracea* L.), carpetweed (*Mollugo verticillata* L.) and cutleaf groundcherry (*Physalis angulata* L.), though all of these weeds were under very good control three years after initiation of no-till. It may be that these were not a major problem because experiment occurred in the fall or because of residual allelopathy from the winter rye. Burgos and Talbert (1996) found that rye, wheat, and rye with hairy vetch suppressed 70-85% of redroot pigweed (*Amaranthus retroflexus* L.) and yellow nutsedge eight weeks after cover crop termination without herbicides, and that rye alone and rye with vetch suppressed 65-70% of large crabgrass (*Digitaria sanguinalis* (L.) Scop.).

Among the winter annual broadleaf weeds, wild radish (*Raphanus raphanistrum* L.) exhibited much greater average groundcover than henbit (*Lamium amplexicaule* L.),

though the average coverage was still less than 2%. Even so, fall mulching was not effective for wild radish control 15 d after application (P=0.6738) in 2008 (Figure 30). The same can be said for all the major weed species present 15 days after mulching during 2008 with the exception of large crabgrass. This may be due to the fact that weed coverage was already under considerably good control after three consecutive years of no-till with high-biomass cover crops, given that even non-mulched control plots exhibited less than 4% coverage of any particular species. The mat of residue on the soil surface after three years of no-till appears to be effective at weed suppression. Figure A5 also shows that while not statistically significant, straw mulch tends to be the best suppressor of the major weed species in 2008, likely due to the thickness of the straw residue.

[Figure A5.]

Average collard yield was 17,900 kg ha^{-1} yr^{-1} harvested as whole heads. Collard yield was not significantly different for any variable, including year (data not shown). This is not unexpected since crop yields are generally more responsive to tillage systems and management than to weed density alone (El Titi, 2003).

In conclusion, weed populations were highly variable, with broadleaf and sedge populations decreasing over three years under the conditions of this study. Furthermore, mulching at 6.7 Mg ha^{-1} yr^{-1} provides a reasonable level of grass control under continuous no-till. Although main crop yields were not affected by application of various organic residues within the first three years of no-till, it seems likely that application of

these residues will improve soil quality over time while simultaneously limiting external inputs. Further studies need to be conducted to determine nutrient cycling efficiency, nutrient relocation and release rates, organic matter accumulation, and C sequestration during continuous high residue no-till with organic mulches. As agricultural sustainability becomes increasingly vital for political and food security around the globe, it is important that obstacles to sustainable food production systems be overcome.

Table A1. Probability of greater F values for the effect of mulch, cover crop (CC), days after mulching (DAM) and year on weed coverage. Treatments not shown or not significant (n/s) were excluded after backward elimination variable selection for the reduced model if P > 0.15.

Effect	P > F		
	Broadleaf	Grass	Sedge
Mulch	0.0913	0.0315	0.0043
Mulch*Year	0.0054	0.1077	0.1046
DAM(Year)	<.0001	<.0001	<.0001
DAM*Mulch(Year)	0.1128	0.0014	0.0008
Year	n/s	n/s	0.0154
CC*Mulch	n/s	n/s	0.0924
CC*Mulch*Year	n/s	n/s	0.1074

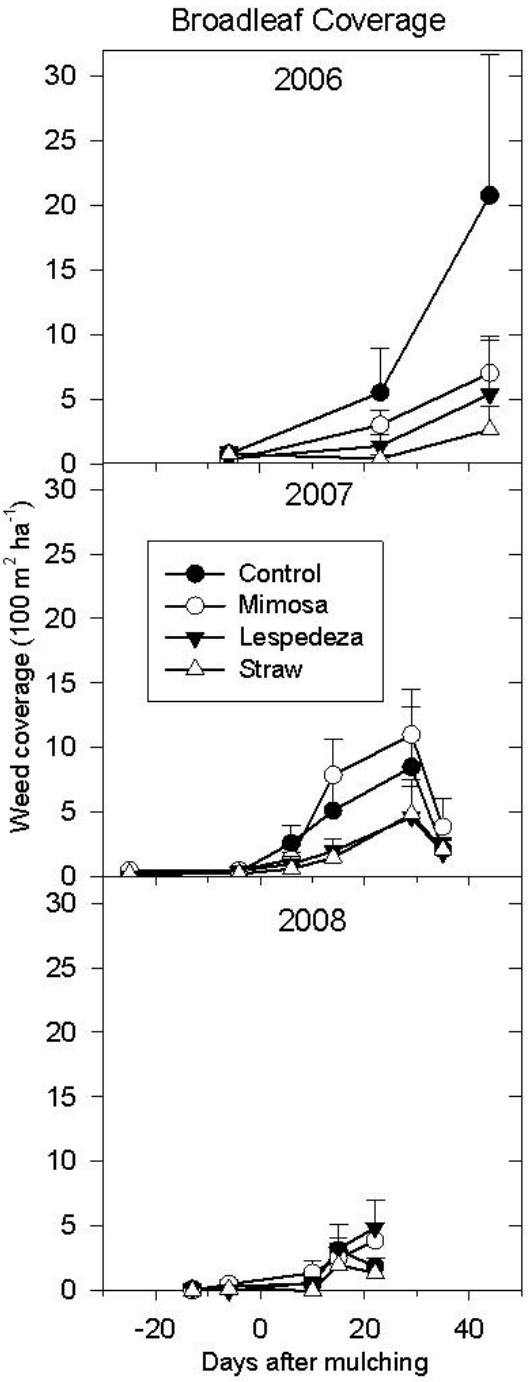

Figure A1. Broadleaf weed coverage after conversion to no-till during 2006-2008 with mulches applied at 6.7 Mg ha^{-1}. Bars represent standard errors of the means.

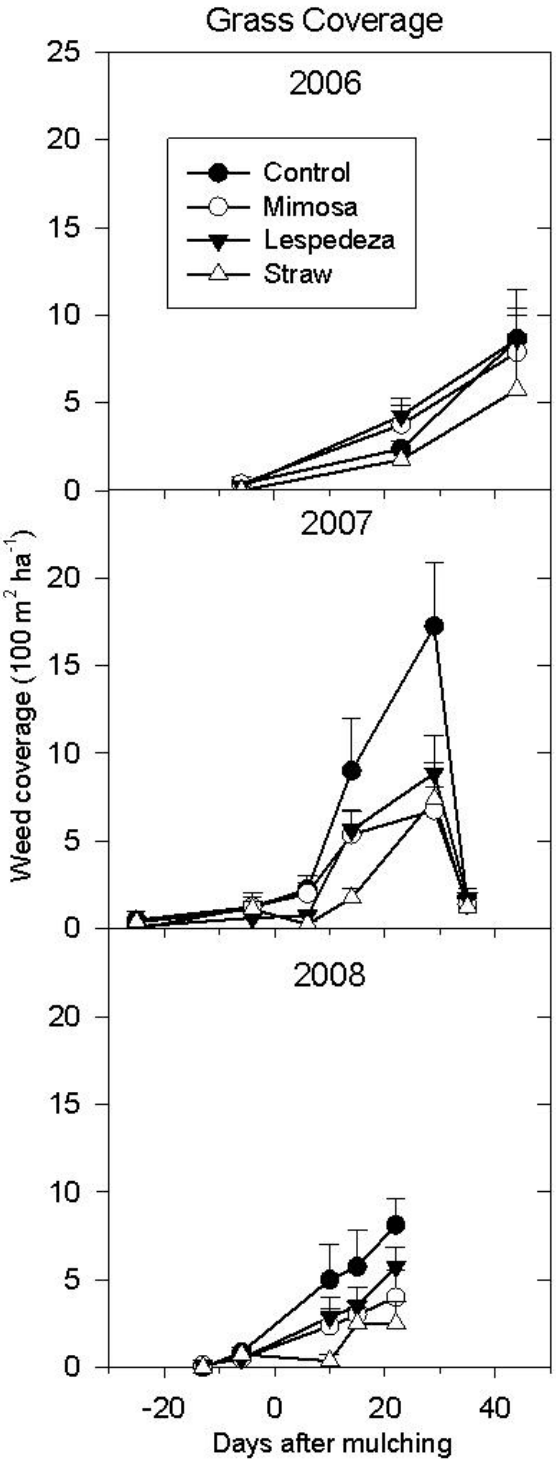

Figure A2. Grass weed coverage after conversion to no-till during 2006-2008 with mulches applied at 6.7 Mg ha^{-1}. Bars represent standard errors of the means.

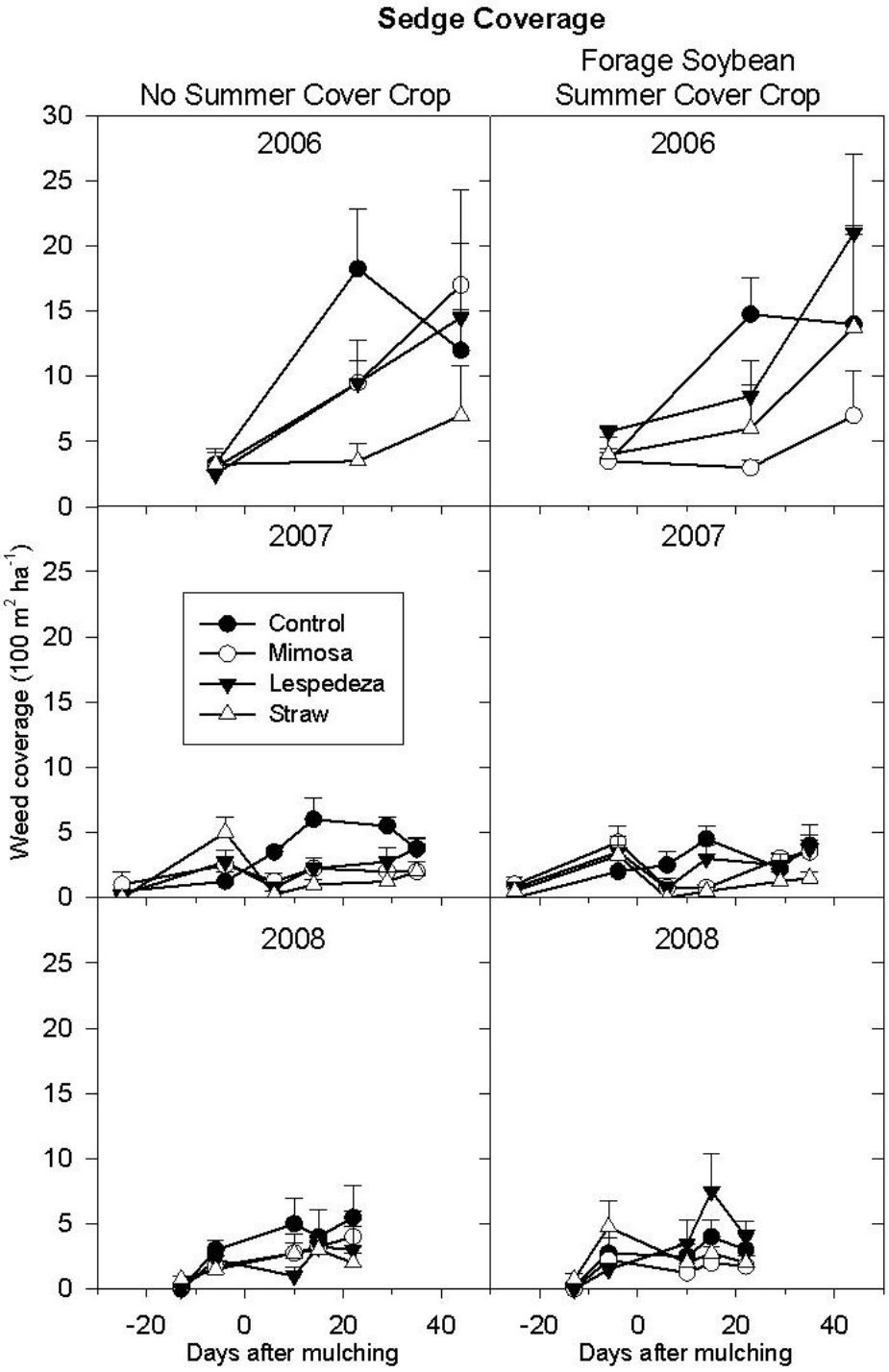

Figure A3. Sedge coverage after conversion to no-till during 2006-2008 with mulches applied at 6.7 Mg ha^{-1}. Bars represent standard error of a mean.

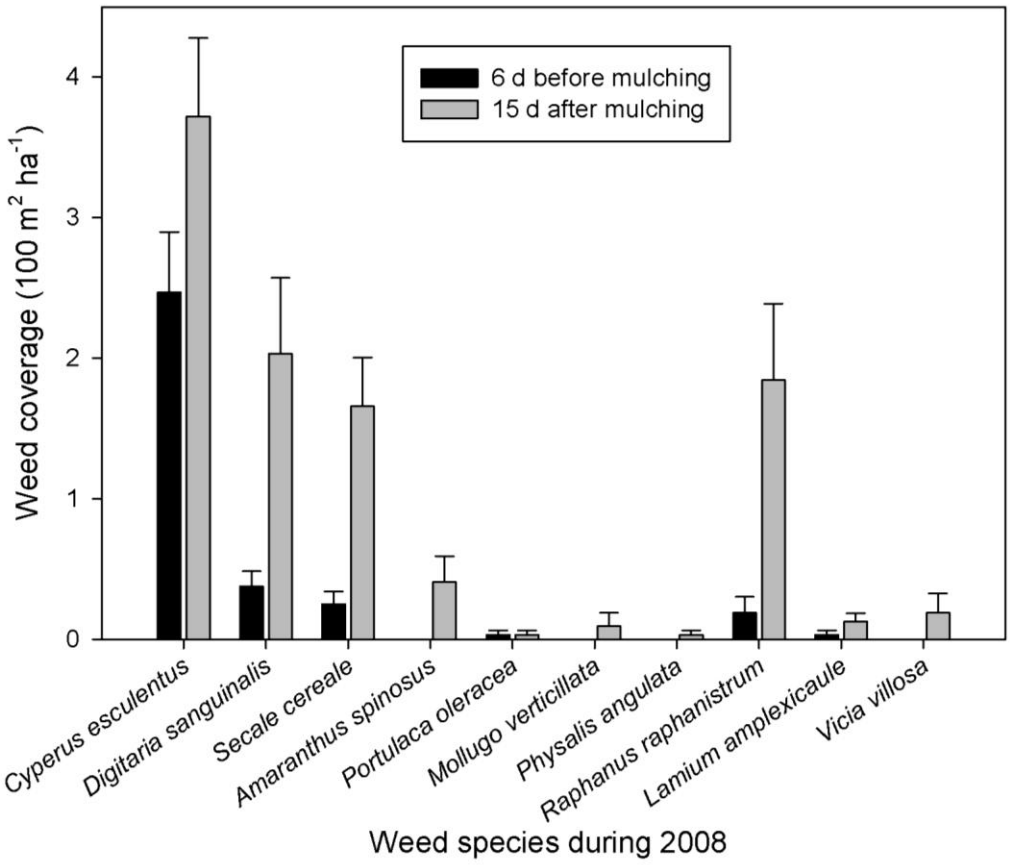

Figure A4. Weed species variation 6 days before and 15 days after mulching three years after conversion to no-till, averaged across experiment plots. Bars represent standard error of a mean.

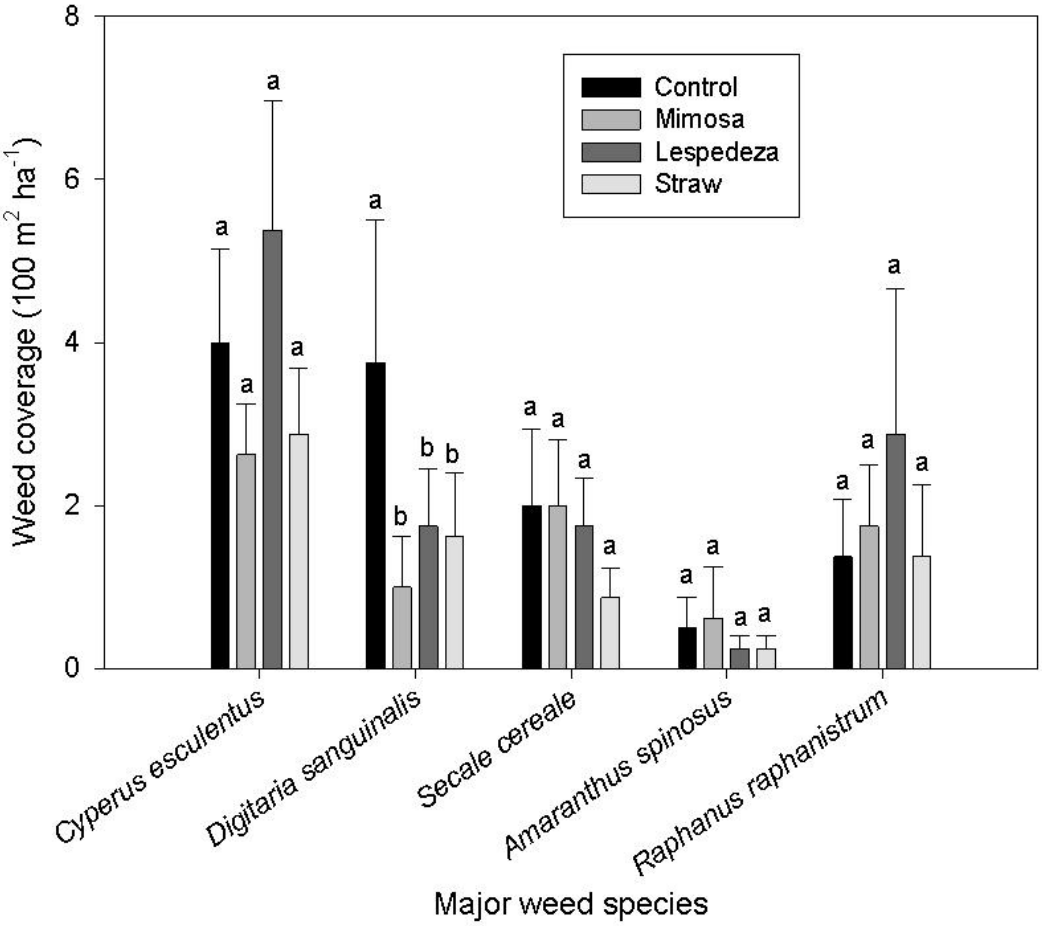

Figure A5. Mulching effects on major weed species 15 days after mulch application during 2008. Bars represent standard errors of the means. Means followed by the same letter within each species were not significantly different at $P > 0.05$.