NITROGEN MINERALIZATION FROM 'AU GOLDEN' SUNN HEMP RESIDUE

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ABSTRACT

The tropical legume sunn hemp (*Crotalaria juncea* L.) cultivar 'AU Golden' has the potential to provide substantial nitrogen (N) to subsequent crops to reduce recommended application rates of synthetic N fertilizers. A mineralization field trial was conducted to measure mass decomposition and N and carbon (C) amounts remaining from sunn hemp residue following three planting dates (May, June, and July) during the 2013 growing season at the Tennessee

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Valley (TVS) and Coastal Plain (WGS) locations of AL. Residue from June and July plantings contained 50.0% and 61.1% N at WGS and 41.5% and 66.5% N at TVS by the end of their respective incubation periods compared to residue from the May planting, which contained 21.1% N at WGS and 47.8% at TVS. In order to create a more synchronous relationship between 'AU Golden' residue N mineralization and crop demand, termination must be delayed until approximate planting of the following crop.

Keywords: Nitrogen, Sunn Hemp, tropical legumes

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INTRODUCTION

Adapted tropical legumes can produce significant biomass and N during short periods of growth (Yadvinder et al., 1992). These characteristics result in superior performance of tropical legumes for equivalent time periods when compared to warm season legumes traditionally utilized in the Southeast. Legumes in crop rotations have regained popularity as conservation efforts look to decrease dependence on synthetic N fertilizers (Holderbaum et al., 1990; Aulakh et al., 1991). However, the amount of N supplied by legume cover crops is unpredictable and reliant on synchronization between residue N release and uptake by the beneficiary crop (Mansoer et al., 1997).

Legumes typically decompose faster than non-legume species due to C:N ratios being less than 20:1 (Cherr et al., 2006). Mineralization of legume residues varies depending on chemical composition of plant parts and maturation stage (Creamer and Baldwin, 2000). Legume leaves and flowers typically have high mineralization potential compared to stems (Marshall et al., 2002; Paul and Clark, 1996). The C:N ratio increases in stems of many legume species as the plant matures, creating more complex C structures that are difficult for soil microorganisms to decompose (Akin, 1989). This often discourages N mineralization and favors N immobilization in microbial biomass (Adams and Attiwill, 1986). Climatic conditions such as high heat and humidity often increase soil microbial activity, which increases residue decomposition and subsequent N mineralization (Cherr et al., 2006; MacDonald et al., 1995). Previous studies suggest that high quality legumes will lose anywhere from 50% to 80% of N within the first two weeks under temperate conditions (Creamer and Baldwin, 2000).

Litterbag methodology has proven to be an effective method of monitoring decomposition rates in the field (Isaac et al., 2000; Mansoer et al., 1997; Mulvaney et al., 2010; Wieder and Lang, 1982). Results of litterbag studies are assumed to represent unconfined decomposing residue exposed to ecological elements representative of field situations (Wieder and Lang, 1982). Litterbags that are commonly made of a nylon mesh material allow for unrestricted residue decomposition in the field while keeping it confined for easy collection (Mansoer et al., 1997). Mulvaney et al. (2010) found this to be an effective method for measuring decomposition of several different high residue organic mulches utilized by no-till vegetable producers.

There has been debate regarding proper approaches for interpreting field decomposition data. Comparisons made by Wieder and Lang (1982) between contrasting statistical analysis approaches found that fitting mathematical models to decomposition data gave a more accurate analysis when the ultimate goal was to determine decomposition rate constants. Isaac et al. (2000) utilized exponential models in order to mirror decomposition of different prunings taken from hedgerow species. Double exponential decay models are thought to best represent decomposition of organic residues in the field because they measure labile, as well as recalcitrant portions of residues during decomposition. Labile fractions that consist of sugars, starches, and proteins are readily expended. Recalcitrant fractions consisting of cellulose, fats, waxes, lignin, and tannins remain behind and decompose at a slower rate, contributing to soil organic matter (Wieder and Lang, 1982).

The majority of sunn hemp N is accumulated in leaf and flower head fractions that easily degrade compared to recalcitrant fractions (Marshall et al., 2002). Wang et al. (2011) reported that sunn hemp residue in past studies had broken down in as little as two weeks; therefore, one should expect peak mineralization to occur in the same amount of time. This was most likely due to rapid decomposition of highly concentrated leaf and flower components (Mansoer et al., 1997). However, lack of synchronization between peak mineralization and crop uptake can result in major N losses through denitrification and leaching (Balkcom and Reeves, 2005).

Utilization of 'Tropic Sun' sunn hemp as an N source has proven beneficial by reducing fertilizer requirements for succeeding crops (Balkcom and Reeves, 2005). However, little is known about decomposition and mineralization of 'AU Golden' sunn hemp. 'AU Golden' can produce seed in temperate climates of the United States, which can improve seed availability and reduce cost (Balkcom et al., 2011). As a result, evaluating this new cultivar's performance, particularly across different planting dates, would be beneficial for this region. Sequestration of N from legumes can be inconsistent due to numerous contributing factors affecting residue decomposition (Cherr et al., 2006). The determination of best management practices for a sunn hemp cover crop is essential to efficiently sequester N for fertilization purposes (Mansoer et al., 1997; Vaughan and Evanylo, 1998). Further knowledge is required on the decomposition rate of 'AU Golden' sunn hemp to properly define management guidelines for producers. The objective of this study was to determine the field decomposition level of 'AU Golden' sunn hemp residue across different planting dates to efficiently utilize it as a N source for a subsequent winter crop.

MATERIALS AND METHODS

A field decomposition study was conducted at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL (34°4' N, 86°53' W) on a Decatur silt loam (Fine, kaolinitic, thermic Plinthic Typic Kandiudults) and at the Wiregrass Research and Extension Center (WGS) in Headland, AL (31°30' N, 85°17' W) on a Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) for the 2013 sunn hemp growing season utilizing litterbag methodology (Bocock and Gilbert, 1957). The field study was imposed on an existing experimental design which was a randomized complete block with main treatments being three sunn hemp planting dates (May, June, and July) with four replications at each location. Individual plot dimensions were 3.0 m wide and 12.2 m long at the TVS location and 3.6 m wide and 12.2 m long at the WGS location with 4.6 m alleys between plots. Sunn hemp was planted at 34 kg ha^{-1} with a 3.0 m wide John Deere® (Deere & Company[1], Moline, IL) conventional drill at TVS on May 24th, June, 25th, and July 26th, and a 3.6 m wide Great Plains® (Great Plains Manufacturing, Salina, KS) no-tillage drill at WGS on May 13th, June 11th, and July 9th. Biomass for the corresponding planting dates was only allowed to accumulate for 60 d, after which sunn hemp was rolled down utilizing a cover crop roller and crimper (Ashford and Reeves, 2003). An application of glyphosate (*N*-(phosphonomethyl) glycine) was then applied to the rolled down sunn hemp to ensure complete termination. The mineralization field trials for May, June, and July planting dates were initiated at WGS on July 9th, August 8th, and September

[1] Mention of a trade name, proprietary product, or specific equipment in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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5th while mineralization field trials at TVS were initiated on July 26th, August 20th, and September 19th.

Residue Collection and Sampling

A designated plot in the existing planting date study was chosen to correspond with each sunn hemp planting date within each replication to impose the mineralization field trial. Prior to termination of each corresponding sunn hemp planting date, a 0.25 m^2 of fresh sunn hemp residue was collected. Nylon mesh bags measuring 10 x 20 cm were utilized in the field to contain the sunn hemp residue designated for observation. Litterbags contained a designated amount of residue for each planting date based on equivalent rates of sunn hemp biomass produced from the previous growing season.

Residue amounts for litter bags at TVS corresponding to May, June, and July planting dates were 8.72, 20.62, and 18.69 g bag^{-1} based on equivalent 2012 yields of 4.4, 10.3, and 9.3 Mg ha^{-1} for each planting date, respectively. Litter bags at WGS corresponding to May, June, and July contained 9.35, 15.97, and 18.84 g bag^{-1} based on equivalent 2012 yields of 4.7, 8.0, and 9.4 Mg ha^{-1}. Residue amounts for the litter bags were estimated based on the dry weight of biomass collected from the 2012 sunn hemp crop, and moisture percentages from a previous study were utilized to estimate residue amounts on a fresh weight basis. Fresh weights from 2012 were used because this allowed fresh residue to be placed in the decomposition bags immediately to correspond with the day of sunn hemp termination. Fresh residue biomass was calculated using a sunn hemp moisture content of 220 g kg^{-1} and adjusted to equivalent rates in g

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bag^{-1}. The appropriate amount of residue was then placed into the litterbags, sealed, and pinned to the soil surface in each designated plot corresponding to each designated planting date for all four replications. Fresh weights of sunn hemp biomass were recorded for the 2013 growing season at both locations to determine the actual moisture percentage, and final reported weights were adjusted accordingly.

Bags were retrieved from the field at 0, 4, 7, 15, 30, 60, 90, and 120 days after sunn hemp termination. The sample time of 120 days corresponded to the maximum decomposition time in the field. For example, May planted sunn hemp was terminated after 60 d, which corresponded to July. The theoretical planting date of a winter crop would be in November, which then corresponded to 120 d field decomposition period. Due to different sunn hemp planting dates and corresponding termination dates, there were a different number of litterbags assigned to each planting date treatment to correspond to the number of days within each incubation period. May litterbags decomposed for 120 days, June litterbags decomposed for 90 days, and July litterbags decomposed for 60 days at both locations to correspond with a theoretical winter crop planting in November.

Once collected from the field, bags were cleaned of any soil and the remaining residue within each bag was oven dried at 55˚ C for a minimum of 72 hours, weighed, and ground to pass a 0.5 mm screen with a Cyclone sample mill (Thomas Scientific, Swedesboro, NJ). Total C and N concentration of the residue was determined through dry combustion using a LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI). Approximately 0.5 g of material from each litterbag was ashed in a muffle furnace at 400˚ C for 12 hours. Data were converted to an ash-free dry weight basis to account for possible soil contamination that might have occurred while in the field (Cochran, 1991).

Statistical Analysis

Percent mass, N remaining, C remaining, and C:N ratio were analyzed using PROC GLIMMIX (SAS Institute, 2012). Treatments were analyzed as a factorial in a randomized complete block design with location, planting date, and sample time as fixed effects while replication was considered random. Treatment means for mass remaining, N remaining, C remaining, and C:N ratios were compared when the F-test was significant ($P \leq 0.05$) by determining the least significant difference (LSD) at 5% probability ($\alpha = 0.05$) across sample times within each planting date and location. Non-linear models were also fitted using SigmaPlot® 12 software (Systat Software, 2010). Equations were single or double exponential models chosen based on their R^2 value. The model with the highest value was considered the best fit and was utilized in all cases. The following equation represents the double exponential decay model:

$Y = Ae^{-k_1 t} + Be^{-k_2 t}$ (Equation 1).

Variables embodied in this equation are as follows: Y= the nutrient or mass remaining, A= labile portion, B= recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t= time in days after termination (Wieder and Lang, 1982).

RESULTS AND DISCUSSION

Different aspects of sunn hemp residue decomposition and nutrient release were affected by location, planting date, sample time, and their interactions (Table 1). Double and single exponential decay models (Equation 1) functioned as the foundation for comparison of percent mass, N, and C remaining after decomposition and were considered significant for mass and N remaining across three planting dates at both locations. Comparisons between k_1 and k_2 values represented in exponential decay models (Table 2) indicated that labile fractions of sunn hemp residue decomposed at a quicker rate compared to recalcitrant fractions. Labile fractions are characterized by starches, sugars, and proteins that are readily consumable while recalcitrant fractions contain material more resistant to decomposition such as cellulose, lignin, and tannins (Mulvaney et al., 2010). The k_1 value representing the fixed decomposition rate of labile portions was consistently higher than k_2 values for percent mass, N, and C remaining across planting dates and locations since labile fractions typically break down immediately during the initial phase of decomposition (Table 2). Single decay exponential models formed in several instances as a result of a small k_2 value, which is indicative of a near linear response that causes the double exponential decay model to collapse into a single exponential model (Table 2).

Residue Decomposition

Field decomposition of sunn hemp residue (with respect to mass) was significantly affected by location, planting date, sample time, and all interactions (Table 1). The percentage of sunn hemp residue remaining after decomposition at WGS was 39.1%, 41.2%, and 52.9% for May, June, and July planted sunn hemp as opposed to 51.2%, 46.9%, and 58.2% at TVS. This indicates a

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more complete decomposition of sunn hemp residue at WGS compared to TVS (Figure 1). This difference in decomposition appeared to occur during the initial weeks of the incubation. A more rapid decomposition at WGS, particularly within the first two weeks after sunn hemp termination, was evident by steeper slopes for the May and June planted residue than for those measured at TVS (Figures 1a and Figure 1b). July planted sunn hemp residue exhibited a steeper initial decomposition slope for TVS but quickly leveled out, while decomposing sunn hemp at WGS continued to decrease in mass (Figure 1c). Over the decomposition period, labile portions decompose; this increases the proportion of recalcitrant components and decreases the overall rate of decomposition (Wieder and Lang, 1982).

A location by planting date by sample time interaction ($p = 0.0005$) was observed for mass remaining (Table 1). Climatic conditions typical to the southern location in Alabama could also explain the accelerated decomposition compared to the northern location where the overall decomposition rate was slower (Figure 2). Temperatures at WGS were usually higher than those at TVS over all three sunn hemp incubation periods, particularly during July, early August, and mid-October (Figure 2). Higher amounts of microbial activity are often typical in environments with high temperatures such as south Alabama, particularly in regard to legume residues that have high amounts of N and subsequent low C:N ratios (Biederbeck and Campbell, 1973; MacDonald et al., 1995) (Table 3). Additionally, May and July planted sunn hemp residue at the TVS location decomposed at a slower rate due to larger recalcitrant fractions (*B*) in comparison to WGS where larger labile fractions (*A*) were present (Table 2). This would also contribute to a slower decomposition rate since residue components more resistant to decomposition (i.e., sunn hemp stems) are degraded less rapidly due to a high C:N ratio (> 20:1) (Table 3) (Mansoer et al., 1997).

Residue corresponding to the July planting date was only allowed to decompose for 60 d and therefore lost the least mass between sunn hemp termination and theoretical planting of the subsequent crop (Figure 1c). Peak mass loss was observed for residue corresponding to the June planting at TVS with losses of 53% while sunn hemp residue corresponding to the May planting at WGS lost as much as 62% (Figures 1a and 1b). Sunn hemp planted in May produced residue equivalent amounts much smaller than those of June and July plantings; this corresponded to the maximum allotted 120 days for decomposition before a theoretical planting of a subsequent winter crop. June planted sunn hemp, regardless of location, produced larger amounts of initial biomass compared to the May planting; therefore, this treatment lost more mass compared to residue from the May planting (Figure 1b). July planted sunn hemp produced the greatest amount of initial sunn hemp residue at each location. However, this residue was only allowed to decompose for 60 d, which resulted in greater amounts of residue remaining compared to the May and June plantings (Figure 1c).

Precipitation fluctuations across locations and incubation periods could also have contributed to rapid residue decomposition. Rainfall was greatest at the TVS location during incubation period 1, while WGS received greater rainfall amounts during incubation period 2 (Figure 3). Studies monitoring temperature and water effects on residue decomposition rates revealed that *k* values increased with increased water application; often to a greater degree during early stages of decomposition when soluble C and N compounds are readily accessible (Schomberg et al., 1994).

Nitrogen Release

Nitrogen released from sunn hemp residue was affected by location, sample time, location by sample time interaction, and planting date by sample time interaction (Table 1). Differences between k_1 values at WGS and TVS revealed a faster N release from May planted sunn hemp at WGS compared to TVS (Table 2). Final litterbags collected from the last sample time at TVS had 47.7% N remaining (Table 3) when compared with residue from WGS for the May planting date which had 21.1% (Figure 4a). June and July planted residue had comparable percentages of N remaining across locations (Figure 4b and Figure 4c).

Nitrogen release from May planted sunn hemp at WGS occurred rapidly, with 35.5% remaining after the first two weeks of incubation period one (Figure 4a). Typically, labile portions are rapidly consumed by microbes, leaving behind recalcitrant fractions that break down slowly, which is depicted by the two pool exponential equations (Mulvaney et al., 2010). The rate constant (A) for labile fractions was higher, indicating rapid mineralization for May planted residue (Table 2). The majority of sunn hemp N is concentrated in leaf and flower fractions. In a previous study, Tropic Sunn rapidly decomposed and, released as much as 50% of its total N in as little as four weeks (Mansoer et al., 1997), which could possibly explain the large amount of N released in the initial phases of decomposition (Table 3). This report was associated with overwintering residue decomposition. In our study, higher N amounts could be lost from 'AU Golden' residue in a shorter period of time due to increased microbial activity associated with higher summer temperatures (Figure 4a).

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June planted sunn hemp residue N release was comparable across both locations, resulting in a near linear decomposition rate (Figure 4b). Similar values were observed for both single exponential models with a slightly higher *k* value at TVS (Table 2). The speed of decomposition can be determined by whether the model corresponds to a single or double decay exponential model. Often, accelerated decomposition results in a single decay model due to an almost linear response of the recalcitrant fractions causing the k_2 rate constant to become very small (Mulvaney et al., 2010).

The initial slope of July planted sunn hemp residue N release at TVS was steeper, indicating a rapid N release that quickly leveled out into a gradual decline, while N release at WGS resulted in a consistent linear decrease (Figure 4c). Incubation period three only lasted 60 d that minimized time for decomposition and N release. Residue from incubation period three at WGS released 38.5% N as opposed to the 33.5% released at TVS (Figure 4c). The two pooled exponential equation indicates decomposition was slower at TVS due to a higher recalcitrant fraction *(B)* (Table 2). Temperatures measured during incubation period three were higher at WGS than at TVS, particularly in early fall (mid-late Oct.), which could have contributed to a more rapid release of N at WGS associated with increased microbial activity (Figure 2).

The majority of sunn hemp N was lost from May planted residue at WGS while June and July planted residue lost 50 and 39% (Table 3) (Figure 4). Nitrogen release at TVS occurred slowly in comparison to WGS. The majority of N release occurred in as little as two weeks after termination, with as much as 64% being released at WGS and over 16% at TVS. Leaf and flower heads of 'Tropic Sun' sunn hemp contain 80.6% of residue N and decompose quickly in comparison to stem fractions that contain less N and are high in lignin and cellulose (Marshall et

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al., 2002). Recalcitrant fractions often encourage immobilization and reduce mineralization (Mansoer et al., 1997). To optimize sunn hemp N contributions, planting of the subsequent crop needs to be synchronized with N release from labile fractions containing the majority of N. Sunn hemp that is allowed to fully decompose prior to planting the subsequent crop would have little N left to contribute.

Carbon Release

Carbon decomposition from sunn hemp residue was affected by planting date, sample time, and planting date by sample time interaction (Table 1). Carbon remaining after incubation periods one and two (May and June planted sunn hemp residue) was comparable at both locations (Figure 5). However, C amounts remaining from incubation period three (July planted residue) was greater, while amounts were 73.7% remaining at TVS compared to 87.9% at WGS (Figure 5). Exponential decay models were not significant for C remaining (%) for June and July planting dates at TVS nor for the June planting date at WGS (Table 2). The k_1 rate constant was higher for May and July planted residue at TVS and for June planted residue at WGS (Table 2). This could be due to higher rainfall that occurred at TVS during incubation period one and incubation period two at WGS (Figure 3).

Higher percentages of C residue were released at TVS from May and June plantings in comparison with that from July due to longer incubation periods as well as heavier rainfall amounts (Figure 3 and Figure 5). Residue from the May and June plantings had 48.5% and 52.3% C remaining, while that from the July planting had 73.7% at TVS (Figure 5). July planted residue appeared to be more resistant to decay due to higher recalcitrant fractions (*B*) in comparison with labile fractions and C was released at a gradual rate (Table 2; Figure 5c). Sunn hemp residue from May and June plantings at WGS similarly had 60.7% and 61.7% C remaining after the designated incubation periods, while July planted residue had 87.9% remaining. May sunn hemp residue released C at a quicker rate than June and July which is evident by the higher rate constant (k_1) and single decay model indicating rapid decomposition (Figure 5a). There was a decrease in C release with later sunn hemp planting dates (Table 3). Observations were indicative of a steady C decline over the residue decomposition period.

CONCLUSIONS

A two pooled exponential decay model showed that labile portions of sunn hemp residue are readily decomposed by soil microbes in comparison to recalcitrant portions that are more resistant to decomposition. Typically, leaf and flower fractions that have a low C:N ratio are readily consumed early during the decomposition phase while stems take longer to break down due to high amounts of complex carbon structures (Mansoer et al., 1997). Results indicate leaf fractions fully decomposed by the end of the mineralization field trial, leaving only sunn hemp stems in the field. Residue from the May planting experienced greater residue and N losses than later plantings, with complete decomposition occurring in some instances. As much as 79% of N was lost from May planted sunn hemp at WGS, while June and July losses were between 39-50%. Sunn hemp planted in July and terminated in September not only had more initial residue, but also less time to decompose. Cooler temperatures later in the season could also contribute to a reduced decomposition rate. There was a greater loss of residue and N at WGS in comparison to TVS as indicated by steeper slopes and greater k_1 values. Accelerated decomposition and N release at WGS may be attributed to higher temperatures and greater amounts of precipitation during certain incubation periods. A more gradual slope was observed for C release across both locations for the three sunn hemp planting dates. June planted sunn hemp at WGS and July planted sunn hemp at TVS had steeper slopes in their decomposition curves at the beginning of the decomposition period before shifting into a gradual decline; this could be attributed to C release from the rapidly decomposing labile fractions. Sunn hemp residue from the May planting date showed the largest amount of C loss compared to residue from the June and July planting dates, which may be attributed to more allotted time for decomposition.

Decomposition, N, and C release occurred at different rates for different sunn hemp planting dates. This was most likely due to different ratios of stem and leaf fractions in litterbags which would decompose at different rates. No attempt was made to put exact proportions of leaves and stems in each decomposition bag. Decomposition of sunn hemp N rich components occurred very rapidly after termination, while organic material with higher C:N ratios (>20:1) decomposed slowly. Sunn hemp residue C:N ratios rose above >20:1 after labile fractions had decomposed and presumably only stems remained. Establishing a synchronous relationship between N release of sunn hemp residue and N uptake by subsequent crops is essential to effectively utilize sunn hemp as a fertilizer source (Dabney et al., 2001). Termination of 'AU Golden' sunn hemp should occur near planting of the following rotational crop so that rapid N release from labile fractions is not lost. Although recalcitrant fractions do not contribute a large

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amount of N for subsequent crops, their contribution to soil surface protection and soil organic matter can also benefit crop production in the long run.

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Table 1. Analysis of variance for sunn hemp residue decomposition measuring percent mass, N, and C remaining and C:N ratio across three locations (LOC) and three sunn hemp planting dates (PD) at various sample times (ST) during sunn hemp decomposition for the growing season of 2013.

	Mass Remaining		N Remaining		C Remaining		C:N Ratio	
	F value	P value	F value	P value	F value	P value	F value	P value
Location	84.27	<.0001	11.48	0.0029	0.76	0.3914	1.07	0.3081
Planting Date	6.66	0.0051	0.30	0.7436	31.52	<.0001	4.33	0.0247
LOC X PD	35.10	<.0001	3.06	0.0696	2.46	0.1108	7.64	0.0057
Sample Time	231.52	<.0001	70.76	<.0001	267.09	<.0001	7.20	0.0000
LOC X ST	6.23	<.0001	2.20	0.0388	1.10	0.3670	1.21	0.3046
PD X ST	13.69	<.0001	12.43	<.0001	49.14	<.0001	3.07	0.0004
LOC X PD X ST	3.01	0.0005	1.21	0.2785	1.01	0.4433	1.24	0.2560

Table 2. Double and single exponential decay equations regressed on time (days) for mass, C, and N remaining from sunn hemp decomposing under field conditions. Residue was obtained from sunn hemp grown for three sunn hemp planting dates (May, June, and July) at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for the growing season of 2013. Double and single exponential decay equations are in the form of $Y = Ae^{-k_1 t} + Ce^{-k_2 t}$ and $Y = Ae^{-k_1 t}$, where Y= mass, C, and N remaining (%), A= the labile portion, C= the recalcitrant portion, k_1 and k_2 are the labile and recalcitrant rate constants, and t= time in days.

Location/ PD†	Equations	R^2	P>F‡	S_{yx}§
TVS	Mass Remaining (%)			
May	$Y = 25.9\ e^{-0.105t} + 78.3\ e^{-0.003t}$	0.8004	0.0234	8.4
June	$Y = 51.3\ e^{-0.036t} + 44.2\ e^{-1.177-019t}$	0.9248	0.0122	5.4
July	$Y = 23.8\ e^{-0.231t} + 76.2\ e^{-0.004t}$	0.9957	0.0026	1.0
	N Remaining (%)			
May	$Y = 62.9\ e^{-0.038t} + 44.8\ e^{-1.43-018t}$	0.7545	0.0351	13.3
June	$Y = 99.2\ e^{-0.010t}$	0.9795	<0.0001	3.2
July	$Y = 18.2\ e^{-0.36t} + 81.9\ e^{-0.003t}$	0.9369	0.0376	2.7

	C Remaining (%)			
May	$Y= 99.2\ e^{-0.007t}$	0.9549	<0.0001	4.5
June	$Y= 97.8\ e^{-0.004t}$	0.9532	0.1111	7.4
July	$Y= 18.4\ e^{-0.531t} + 81.6\ e^{-0.002t}$	0.9120	0.0523	2.8
WGS	Mass Remaining (%)			
May	$Y= 67.1\ e^{-0.073t} + 35.0\ e^{-4.42-019t}$	0.8984	0.0062	8.6
June	$Y= 56.8\ e^{-0.096t} + 44.6\ e^{-0.002t}$	0.9394	0.0089	5.9
July	$Y= 51.6\ e^{-0.0559t} + 49.1\ e^{-5.86-019t}$	0.9582	0.0250	3.9
	N Remaining (%)			
May	$Y= 73.0\ e^{-0.192t} + 27.0\ e^{-0.003t}$	0.9779	0.0003	4.2
June	$Y= 96.4\ e^{-0.0087t}$	0.7100	0.0107	11.9
July	$Y= 94.3\ e^{-0.007t}$	0.6589	0.0310	8.3

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		C Remaining (%)						
May		Y= 94.6 $e^{-0.005t}$		0.7746		0.0024		8.3
June		Y= 26.1 $e^{-0.113t}$ + 74.8 $e^{-0.003t}$		0.6915		0.0979		9.4
July		Y= 94.3 $e^{-0.007t}$		0.6589		0.0309		8.3

† Planting date.

‡ Significance of regression.

§ Standard error of the estimate Y on X.

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Table 3. Dry weight, carbon (C), nitrogen (N), and the C/N ratio of sunn hemp residue measured across a decomposition periods for three sunn hemp planting dates at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the year of 2013.

			TVS					WGS			
Planting Date	Time†		Dry Wt.	C	N	C/N Ratio		Dry Wt.	C	N	C/N Ratio
	days		---g---	-----g kg^{-1}-----				---g---	-----g kg^{-1}------		
May	0		1.97	448.9	17.8	26.8		1.69	442.3	47.9	9.3
	4		2.18	417.1	19.0	22.8		1.52	402.0	29.9	14.7
	7		1.88	419.1	14.3	31.4		1.28	407.5	19.5	25.9
	15		1.38	399.3	15.0	27.0		0.88	372.7	17.0	31.6
	30		1.39	294.8	9.0	33.6		0.82	389.6	11.1	36.3
	60		1.47	314.3	8.6	37.6		0.42	240.3	10.1	24.3
	90		1.13	222.3	8.9	25.5		0.66	269.7	10.6	26.2
	120		1.01	205.5	8.5	25.0		0.66	267.9	10.1	17.7
$LSD_{0.05}$			0.45	120.0	5.9	12.7		0.42	64.7	5.2	16.8

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June	0		4.81	457.2	25.8	17.8		3.85	458.2	20.0	23.2
	4		3.90	415.4	27.5	15.1		3.35	419.6	23.0	18.4
	7		4.07	416.2	22.5	18.9		2.78	403.0	20.1	20.4
	15		3.69	414.6	21.7	19.4		2.03	314.5	12.3	25.3
	30		3.02	391.0	19.0	21.0		1.90	283.2	10.5	26.3
	60		2.33	307.9	14.0	21.8		1.39	245.5	11.2	21.4
	90		2.26	239.3	10.7	22.4		1.59	283.2	10.0	27.0
$LSD_{0.05}$			0.30	53.4	3.8	4.0		0.63	168.8	5.9	10.9
July	0		5.38	474.6	23.9	20.7		4.20	455.1	26.2	17.5
	4		4.54	398.3	19.8	20.2		3.73	425.3	19.9	48.7
	7		4.23	375.1	18.8	20.0		3.63	425.0	25.6	17.1
	15		3.83	390.3	18.5	21.2		3.07	421.1	21.8	19.6
	30		3.63	358.6	16.3	22.3		2.30	426.5	20.5	20.8
	60		3.12	350.0	15.9	22.1		2.22	400.0	16.0	25.2
$LSD_{0.05}$			0.50	42.3	4.2	4.3		0.39	44.6	8.1	38.7

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† Days after bags were placed in the field; day 0 corresponds to the day the bags were placed in the field.

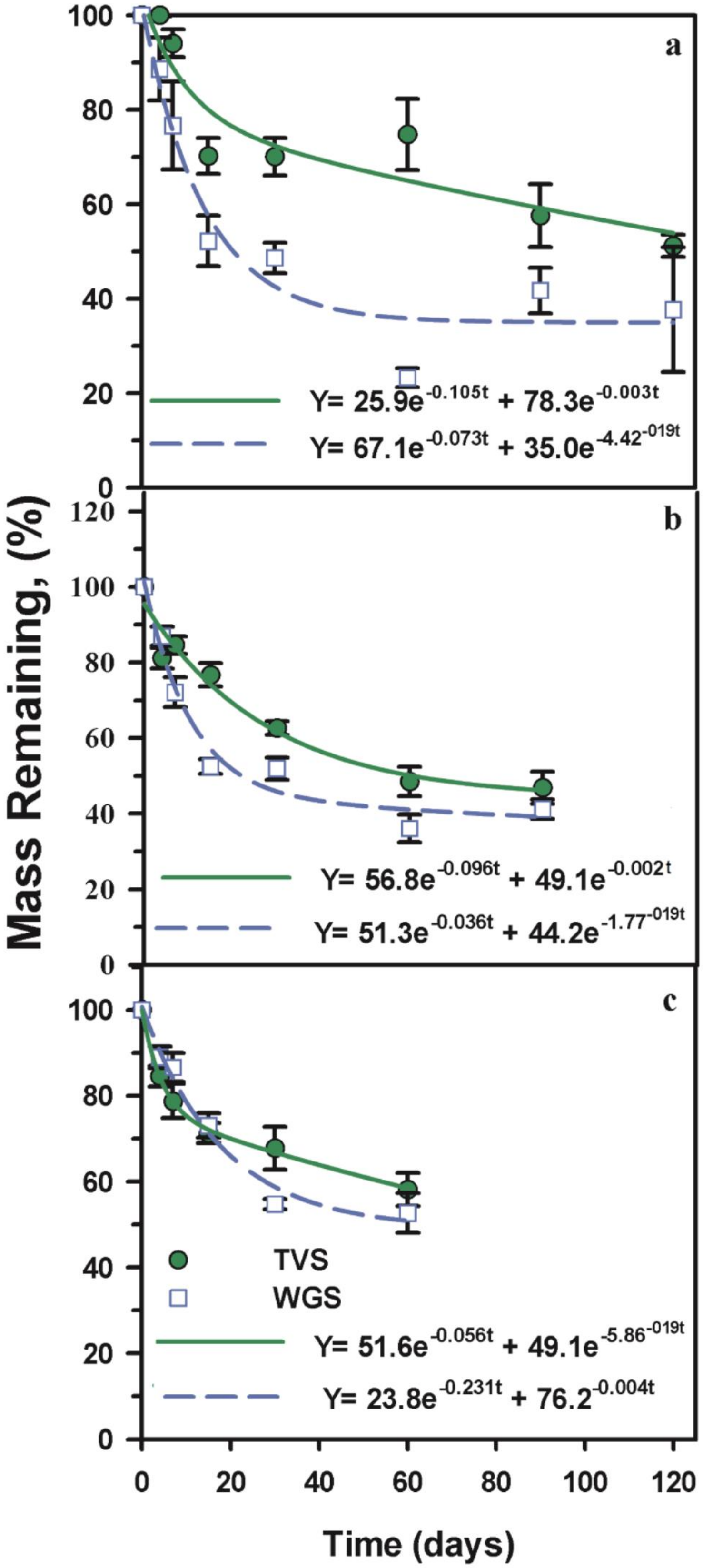

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Figure 1. Comparisons between the exponential decay of sunn hemp residue across seven sample times (days) for May (a), June (b), and July (c) planted sunn hemp at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season. Error bars represent standard errors of the mean

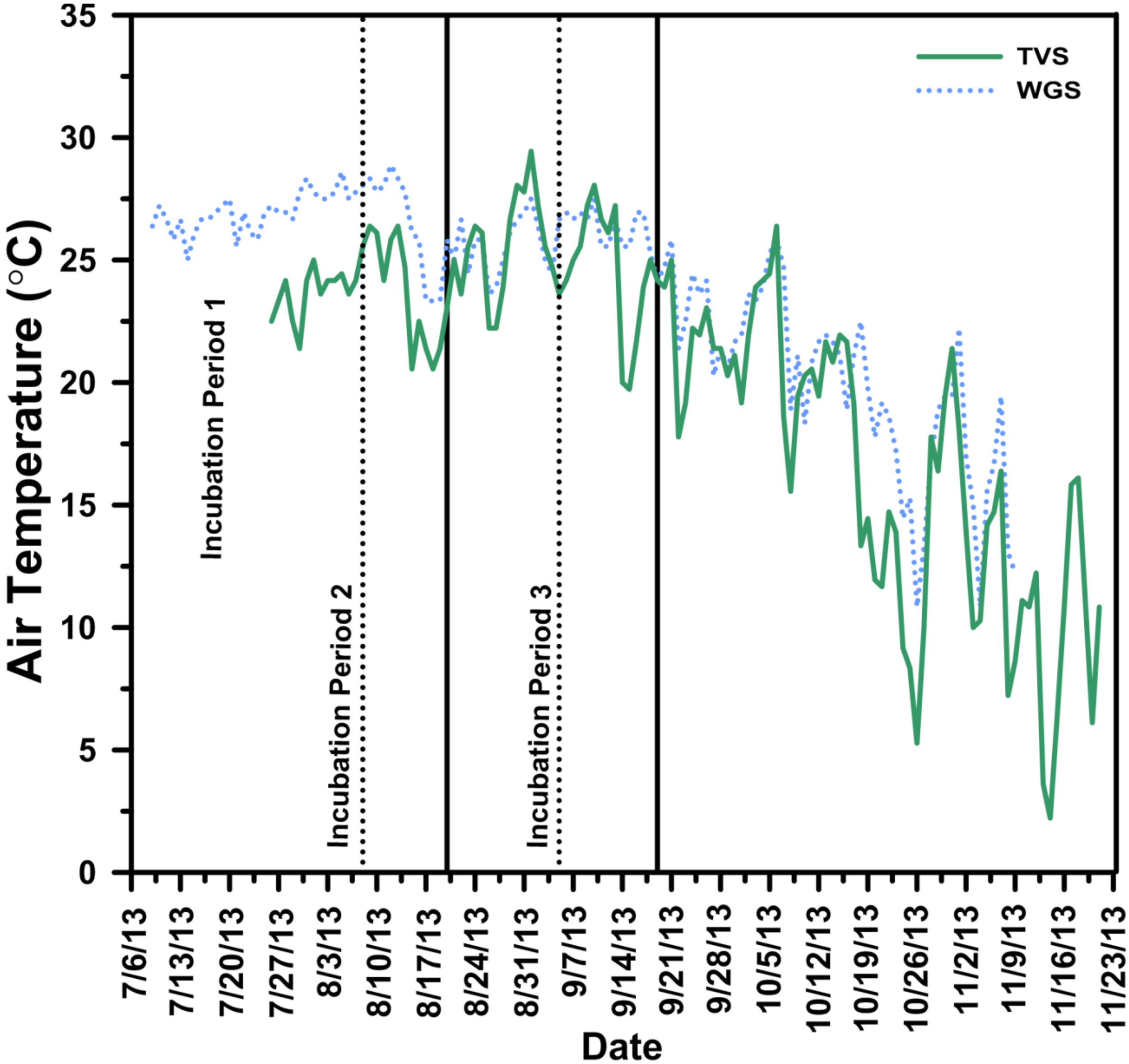

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Figure 2. Daily average air temperature measured at the Tennessee Valley Research and Extension Center (TVS) and the Wiregrass Research and Extension Center (WGS) during three sunn hemp incubation periods that correspond to three sunn hemp planting dates. Solid (TVS) and dotted (WGS) vertical lines correspond to the initiation of each decomposition period for the corresponding planting date at a particular location. All three incubation periods began 60 d after the corresponding sunn hemp planting date

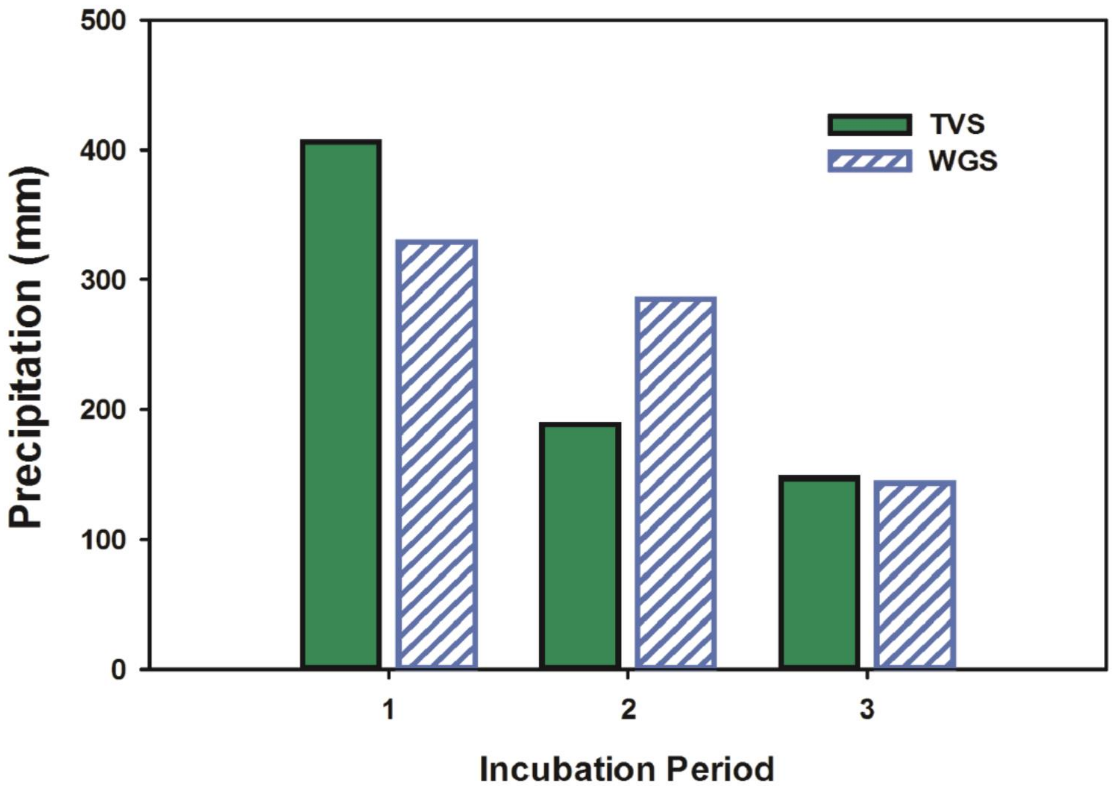

Figure 3. Daily precipitation averaged over three decomposition periods corresponding to three sunn hemp planting dates (May, June, and July) at the Tennessee Valley Research and Extension Center (TVS) and at the Wiregrass Research and Extension Center (WGS) during the 2013 growing season. Each incubation period began 60 d after the corresponding sunn hemp planting date

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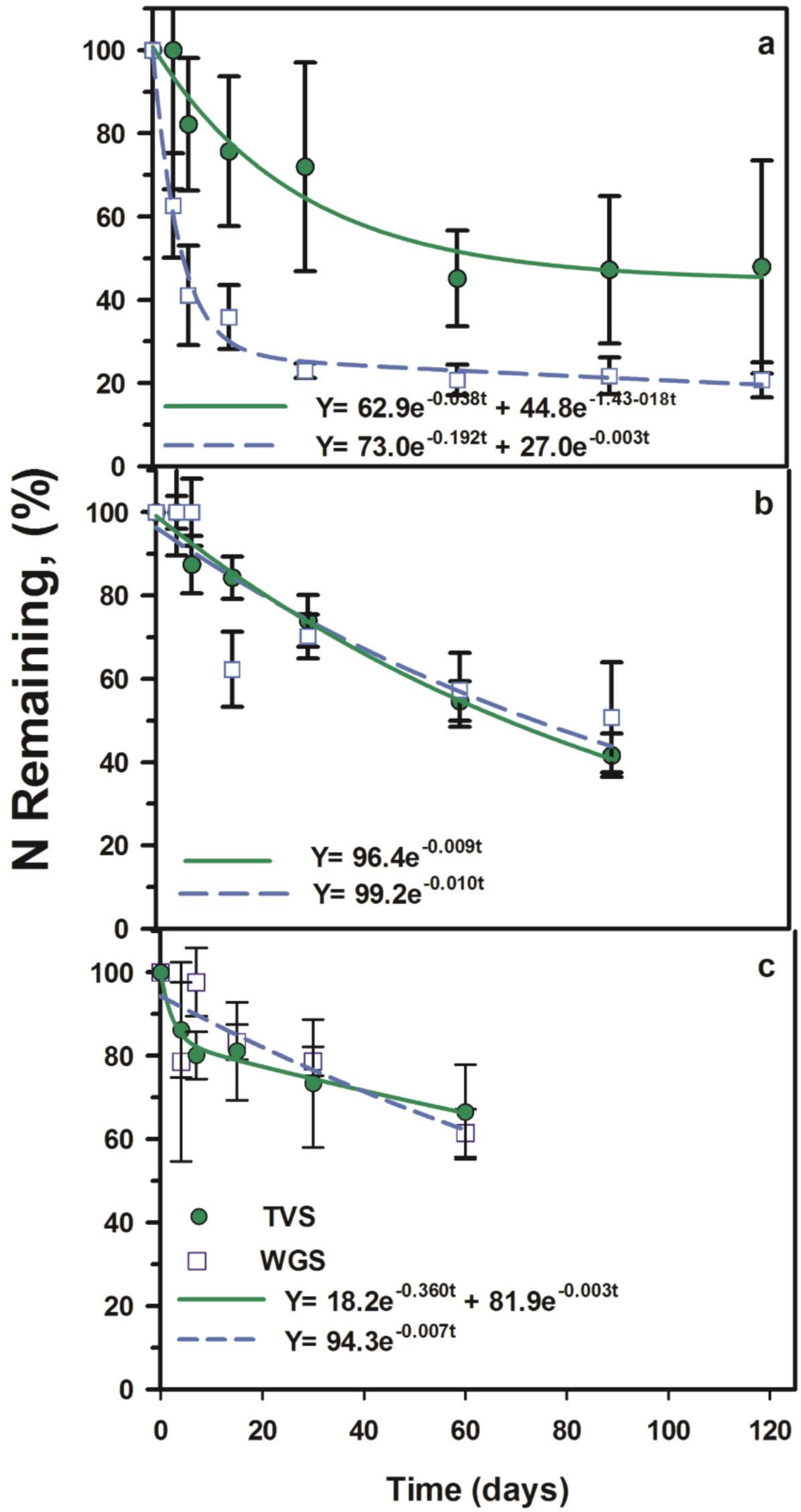

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Figure 4. Comparisons between the release of N from sunn hemp residue across seven sample times (days) for May (a), June (b), and July (c) planted sunn hemp at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season. Error bars represent standard errors of the mean

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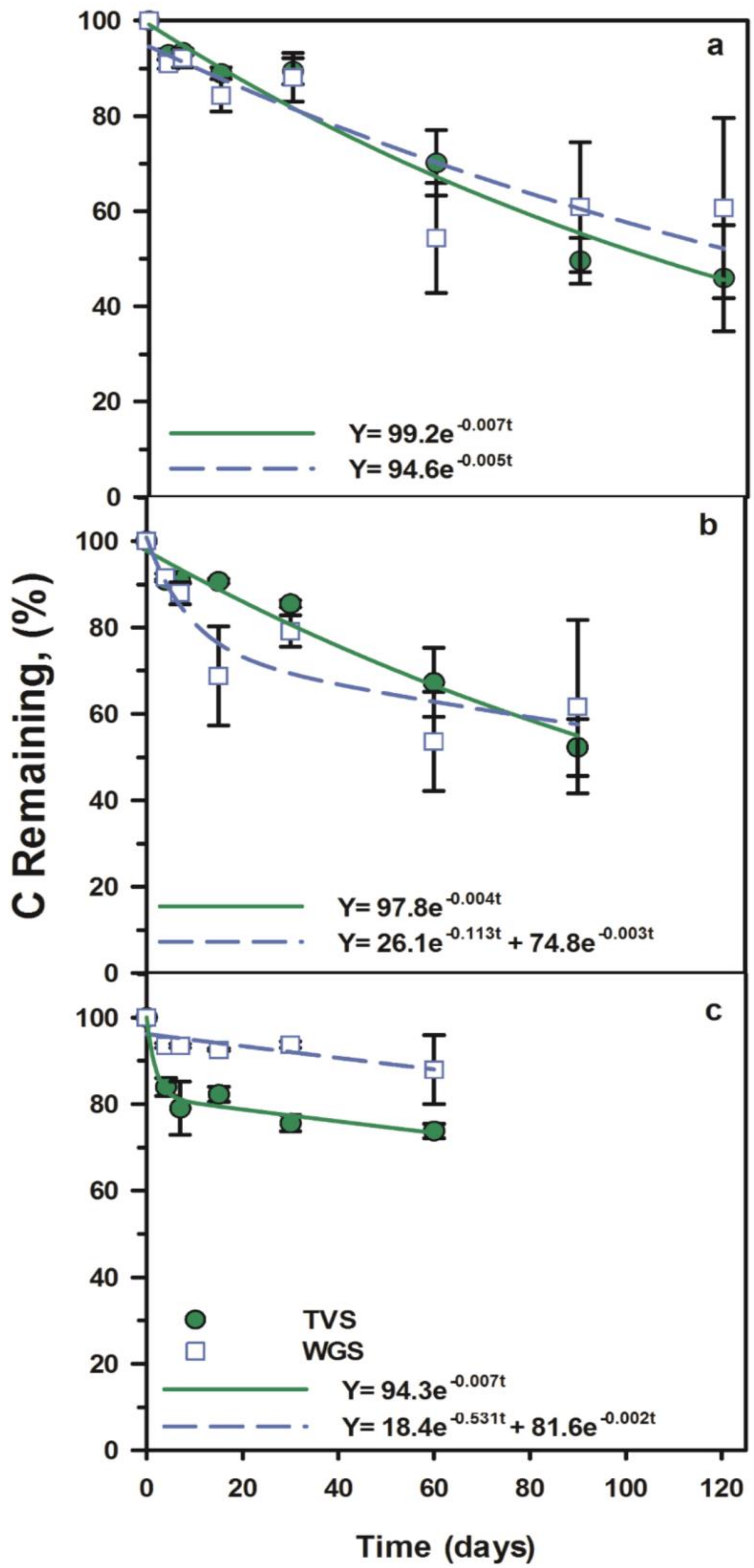
a
b
c
C Remaining, (%)
Time (days)
Y= 99.2e^-0.007t
Y= 94.6e^-0.005t
Y= 97.8e^-0.004t
Y= 26.1e^-0.113t + 74.8e^-0.003t
Y= 94.3e^-0.007t
Y= 18.4e^-0.531t + 81.6e^-0.002t
TVS
WGS
0
20
40
60
80
100
120

Figure 5. Comparisons between the release of C from sunn hemp residue across seven sample times (days) for May (a), June (b), and July (c) planted sunn hemp at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season. Error bars represent standard errors of the mean

