

Nutrient Dynamics and Decomposition of Riparian *Arundinaria gigantea* (Walt.) Muhl. Leaves in Southern Illinois

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Abstract

Leaf litter quality and quantity can influence soil nutrient dynamics and stream productivity through decomposition and serving as allochthonous stream inputs. Leaf deposition, nitrogen (N)-resorption efficiency and proficiency, and decomposition rates were analyzed in riparian stands of *Arundinaria gigantea* (Walt.) Muhl. in southern Illinois for the first time to determine potential nutrient cycling from riparian canebrake restoration. Leaf litter was collected from five established canebrakes monthly over one year and a decomposition study was conducted over 72 weeks. Live leaves, freshly senesced leaves, and decomposed leaves were analyzed for carbon (C) and N content. Leaf litterfall biomass peaked in November at twice the monthly average for all but one site, indicating a resemblance to deciduous leaf fall patterns. Nitrogen and C concentrations decreased 48% and 30%, respectively, between live leaves and 72 weeks following decomposition. High soil moisture appeared to slow decomposition rates, perhaps due to the creation of anaerobic conditions. Cane leaves have low resorption proficiency and nutrient-use proficiency, suggesting that these riparian canebrakes are not N limited. Giant cane should be considered in multispecies riparian buffer creation since it has this potential to supply carbon and nitrogen to the soil and to macroinvertebrates in the streams for a longer period of time and year round.

Keywords: Giant cane, leaf litterfall, N efficiency, N proficiency, leaf decomposition

1. Introduction

The deposition, composition, and decomposition of leaf litterfall are important components of nutrient cycling. Inorganic nitrogen (N) is made available for plant uptake through mineralization of N contained in dead organic matter, while providing energy for microbial metabolism (Perez et al., 2003). Litter decomposition provides the primary source of mineral N for biological activity in most terrestrial ecosystems (Parton et al., 2007). The fraction of N that becomes available for the growth of plants depends on the ratio of total carbon (C) to total N in the mineralized substrate (Rosswall, 1982; Perez et al., 2003). Ratios of C to N in litter affect soil processes, including the rates of net N mineralization of organic matter and decomposition and the availability of soil nutrients in forest ecosystems (Scott & Binkley, 1997; Fassnacht & Gower, 1999; Ferrari, 1999; Perez et al., 2003).

Litter C:N ratios indicate N-use efficiency (NUE) and can control ecosystem N cycling in soil (Perez et al., 2003). Resorption efficiency can be quantified as the percentage of a given nutrient translocated from leaves before abscission (Aerts, 1996). High resorption efficiency provides a considerable adaptive advantage since it allows species to be less dependent on the uptake of soil nutrients, reducing their losses and increasing the efficiency of their assimilation (Salazar et al., 2011). The NUE of litter production in an ecosystem is a combination of the species assemblage properties in that ecosystem (Perez et al., 2003). Another parameter employed to quantify nutrient cycling is nutrient-use proficiency (NUP) of resorption, which is defined as the minimum level to which plants can reduce an element in their leaves before leaf senescence (Killingbeck, 1996).

There are limited studies which evaluate NUE and NUP in riparian plant species. Southern Illinois offers an ideal study area to examine leaf litter characteristics of a unique riparian zone species, giant cane [*Arundinaria gigantea* (Walt.) Muhl.]. Historically, cane was an important habitat of lower midwestern and southeastern United States' riparian areas, including southern Illinois (Platt & Brantley, 1997; Brantley & Platt, 2001; Schoonover & Williard, 2003; Platt et al., 2009). Giant cane now persists in narrow strips along floodplains of streams and rivers, and, as such, may be a considerable contributor of allochthonous material to streams.

Presented in this paper are the dynamics of litterfall and a discussion of NUE, NUP, and decomposition of canebrake leaves in southern Illinois. Research questions addressed include: (i) how do litterfall dynamics and NUE relate to the internal N cycling in each canebrake?; (ii) how does litterfall nutrient composition relate to decomposition in canebrakes based on C:N ratios and N recovery from leaf tissues before leaf fall?

2. Methods

2.1 Site Description

The Cache River watershed has mixed forest vegetation with *T. distichum* var. *distichum* L. in the wetlands and Oak-Hickory forests. The dominant soil association was Haymond-Petrolia-Karnak, which is formed from sandy to clayey alluvial sediments often found in bottomlands (ISGS, 1984). The mean annual rainfall over the past ten years for the area is 127 cm with a mean annual air temperature of 13.9 °C (ISWS, 2012).

Five canebrakes on Cypress Creek National Wildlife Refuge property within the Cache River watershed in southern Illinois were chosen, including two canebrakes on the Bellrose Waterfowl Preserve, two on the Hickory Bottoms property, and one on the Buttonland Swamp/Lower Cache Access property (Figure 1). One of the Bellrose canebrakes and the Buttonland canebrake were used as the sites and source material for the decomposition study. The Buttonland property was located at the edge of a bottomland forest and often inundated, while Bellrose was at a slightly higher elevation and slope. Soil textures were similar among all sites (silt loam, Nelson, 2014).

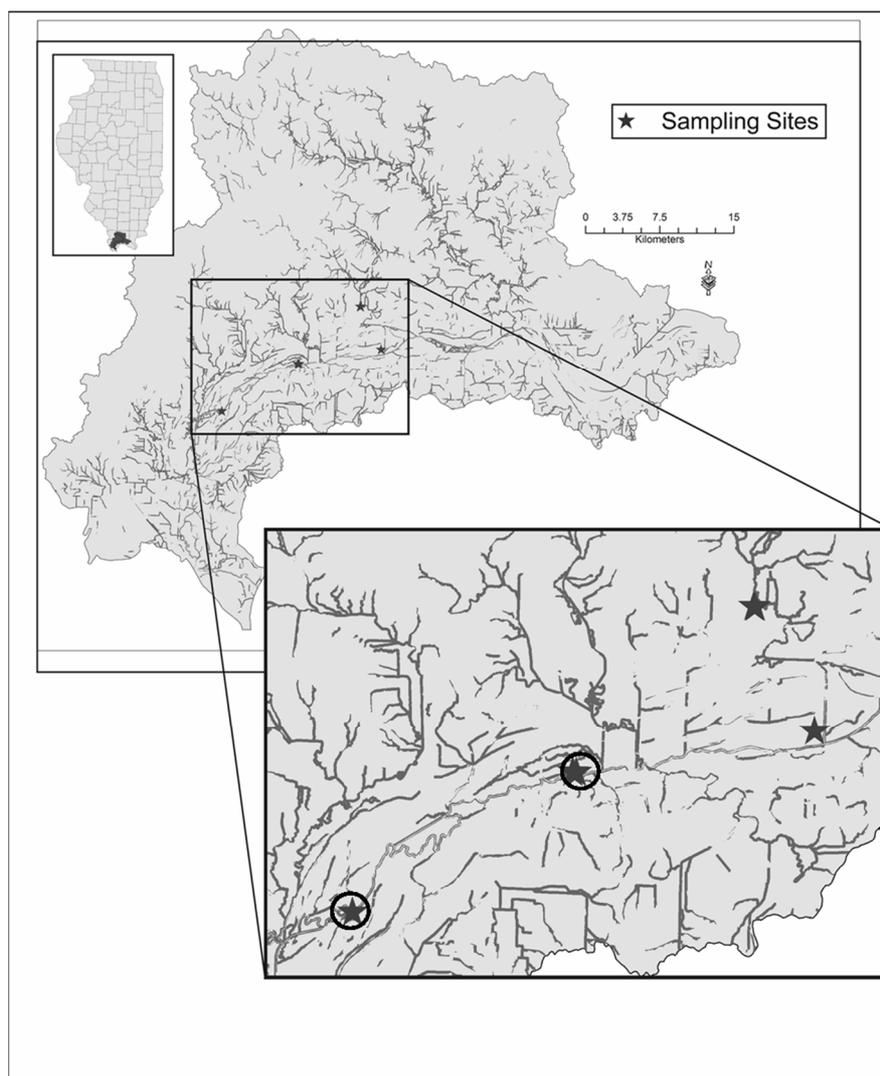


Figure 1. The canebrake leaf litter collection sites in the Cache River watershed, southern Illinois (2011-2013). Decomposition sites are circled

2.2 Leaf Deposition

Between July 2011 and September 2012, litter material was collected monthly from eight litterfall traps in each of five canebrakes. Litterfall traps composed of round plastic laundry-type baskets with a diameter of 0.4 m (0.126 m², with two rows of vertical openings 3 cm by 10 cm) were placed randomly, at least one m from the edge of the canebrake. The collection basket had five ½-cm drainage holes drilled in the bottom and was staked so that the basket sat above the ground level. Monthly inputs of fine litter biomass were collected, dried (85 °C, 48 hours), weighed, and expressed as g dry mass m⁻².

Litter samples from each canebrake were ground separately by hand with a mortar and pestle until homogenous and analyzed using a Thermo FLASH 2000 NC Soil Analyzer (Thermo Scientific, Waltham, MA) following the methods described in Sparks (1996) to determine percent C and N concentrations to calculate nutrient efficiency and resorption proficiency and C:N ratios. N fluxes related to fine litterfall were obtained by multiplying the concentration of total N in litter samples by the biomass input for each month (Perez et al., 2003). Although leaching of C and other nutrients, and some decomposition of biomass may have occurred as the litter sat inside the traps for one month before processing, these processes were assumed to be identical for all traps (Sparks et al., 1996; Perez et al., 2003).

2.3 Live Leaf Composition

In each canebrake, fresh leaves of at least three cane culms were taken from branches approximately 1.5 m above ground level in August and October 2012. Samples were air-dried (24 hours), ground by hand with a mortar and pestle until homogenous, and analyzed for total C and N concentrations using the same methodology described for litter material. For each canebrake the average index of internal retranslocation, which was estimated as the difference between foliar N concentration and litterfall N concentration, was calculated (Chapin, 1980; Vitousek, 1982; Veneklaas, 1991). The percentage of N retranslocated (% RT) was calculated as:

$$\% \text{ RT} = (\% \text{ N leaves} - \% \text{ N litterfall}) / \% \text{ N leaves} * 100.$$

% RT is a direct estimate of species NUE, that is, a high % RT coincides with a high NUE (Vitousek, 1982). Mean retranslocation values were the averages of all seasonal values (Perez et al., 2003).

Considering environmental constraints on % RT (Killingbeck 1996), two additional indices were used to estimate NUE (Perez et al., 2003). First, following Vitousek's (1982) definition of NUE as the amount of organic matter lost (in litterfall or root turnover) or stored (biomass increment) per unit of nutrient lost or stored, C:N ratios of litterfall for the canebrakes were used as indicators of NUE at the species level. Finally, the concentration of N in litter (%) was used as an index of NUP at the species level. This index estimates the absolute level to which nutrients are reduced in senescing leaves (Killingbeck, 1996; Perez et al., 2003). Values less than 0.7% indicate a high resorption proficiency (Killingbeck, 1996; Perez et al., 2003).

2.4 Decomposition

Decomposition rates were determined using the litterbag technique of Swift et al. (1979) to estimate mass loss rates and leaf litter nutrient dynamics. Senesced leaves were collected during fall 2012 from two canebrakes (Access and Bellrose 1). Leaves were kept separated by canebrake and then air dried for 2 weeks. Nylon litterbags with 5 mm and 1 mm openings on the top and bottom, respectively, were used and each contained approximately 10 g of air-dry whole leaf litter. The larger upper mesh was used to allow terrestrial arthropods access to the tree litter and the smaller bottom mesh prevented the loss of small fragments (Parton et al., 2007; Nikula et al., 2010). Two sets of bags, one with each source of canebrake leaves, were installed at the canebrake sites November 2, 2012 and were placed on the canebrake floor with bags comprising each set lying in close proximity (all within a 10 m² area). Temperature and moisture in the upper 10 cm of the soil of each plot were monitored every 30 minutes with Spectrum WatchDog (Plainsfield, IL) data loggers.

At each collection time (0, 1, 2, 4, 8, 12, 24, 36, 48, 60, and 72 wk), two bags (one from each set) were collected from each plot. Bags collected at time 0 were utilized to estimate handling and moisture loss. Litterbags were transported to the laboratory on ice in labeled resealable plastic bags. In the laboratory, litter was gently rinsed with deionized water to remove soil and other debris, oven-dried at 70 °C for 72 h and weighed.

2.5 Statistical Analysis

Analysis of covariance (ANCOVA) was used to test differences among both sites and sources of decomposition. Multiple Comparison Tukey test was used to separate the means when a significant difference was found. A regression was performed with time on the natural log of percent mass remaining. The slope of that regression was the negative mass loss coefficient (k) (Swift et al., 1979). Pearson correlation was used to test for relationships

among site variables (soil moisture and temperature), litter quality, and k values. All statistics were considered significant at $\alpha = 0.05$. All statistical analyses were run using JMP 10.0 software (Cary, NC).

3. Results

3.1 Leaf Deposition

Litter deposition in all canebrakes was continuous throughout the year, but there was a statistically higher rate of litterfall on the December 1, 2011 collection day, indicating a higher rate in the month of November (549.5 kg ha^{-1} compared to a mean of 268.0 kg ha^{-1} for the remaining months) (Figure 2). There were no differences in C or N concentrations or C:N ratios of deposited materials across time (means of $3.80 \pm 0.53 \text{ mg C}$, $0.16 \pm 0.04 \text{ mg N}$, $24.21 \pm 5.30 \text{ C:N}$). The calculated %RT was 8.81. The resorption proficiency was 1.58%.

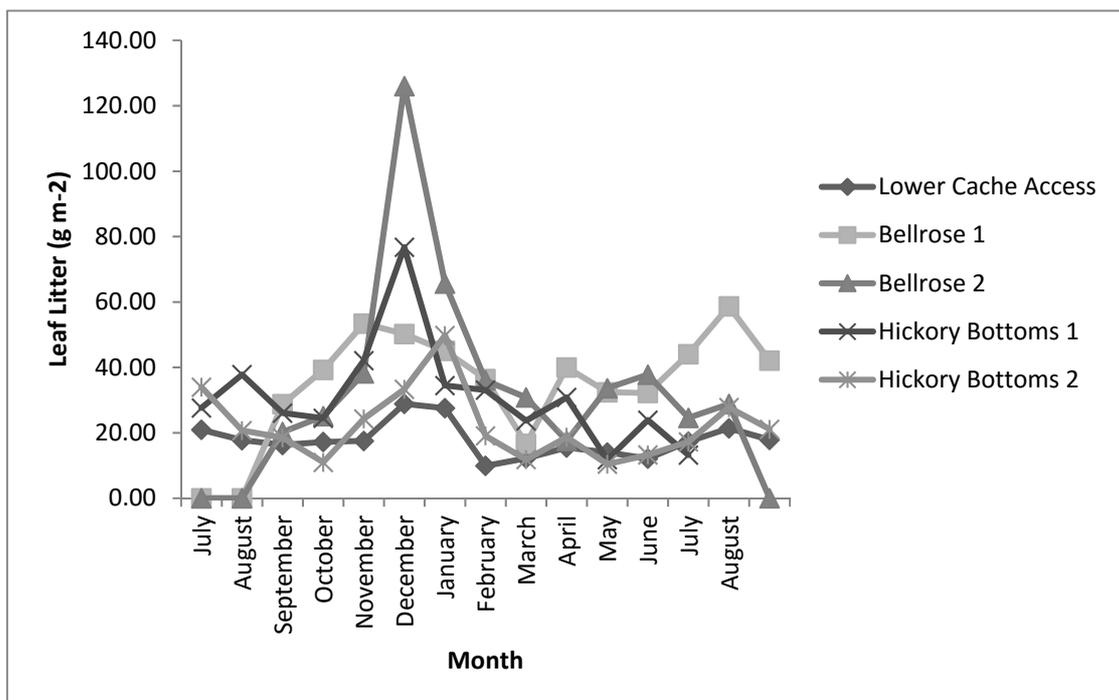


Figure 2. Leaf litter deposition quantities in canebrakes in southern Illinois, July 2011 to September 2012

3.2 Leaf Nutrient Content

The concentrations of C and N and C:N ratios in freshly fallen litter were not different ($p > 0.10$) among sites. There were significantly different concentrations of carbon (mg C g^{-1}) between live leaf (43.08 ± 1.23), freshly senesced leaf carbon levels (37.97 ± 0.57), and 72-week decomposed leaves (31.01 ± 0.37) (Figure 3). This indicates a loss of 18% between fresh leaves and senesced and a 12% loss during 72 weeks of decomposition, for a total loss of 30%. There was no difference in N concentrations (mg N g^{-1}) between fresh leaves (1.72 ± 0.19) and freshly senesced (1.58 ± 0.04), but there was a difference when decomposed leaves were compared to both fresh and freshly senesced leaves (0.97 ± 0.19) (Figure 4). There was a 48% total loss of N from fresh leaves to 72 weeks decomposed.

3.3 Decomposition

There was no difference in decomposition rates across leaf sources ($p = 0.382$), but there was a difference between the decomposition sites ($p = 0.033$) (Figure 5). There was no difference in soil temperature across sites ($p = 0.986$), but there was a trend in soil moisture (volumetric water content, % VWC, $p = 0.0580$). The site with the higher soil water content (31.1% VWC) had the lower k (-0.00115), while the site with the lower soil water content (25.3% VWC) had the higher k (-0.00135).

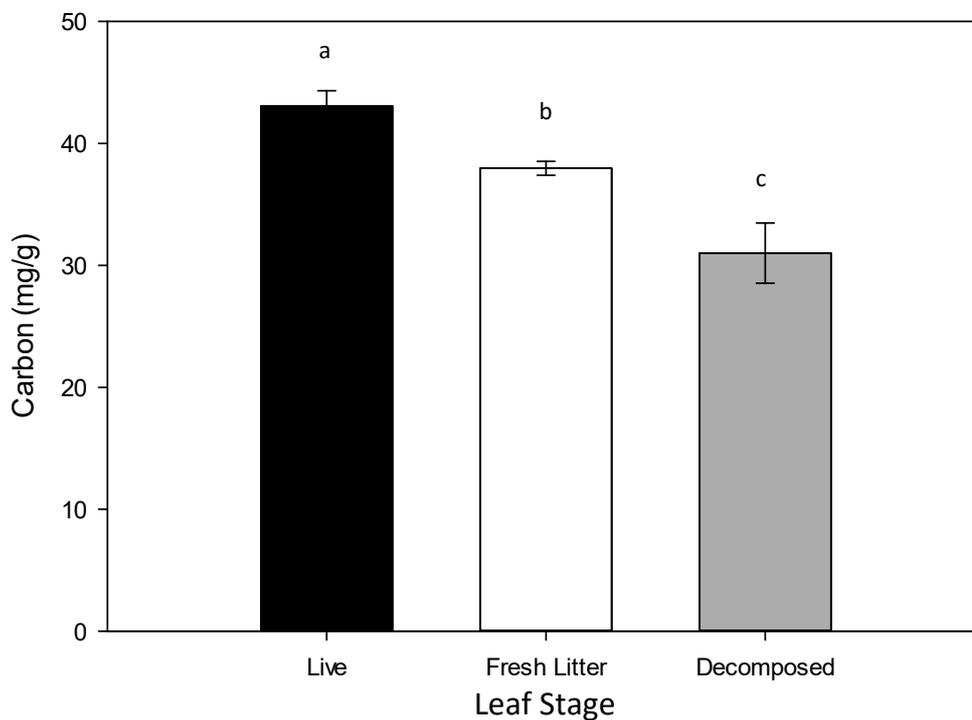


Figure 3. Carbon concentrations in live, freshly senesced, and 72-weeks decomposed giant cane leaves in southern Illinois (2011-2013). Means with dissimilar letters differ ($\alpha = 0.05$)

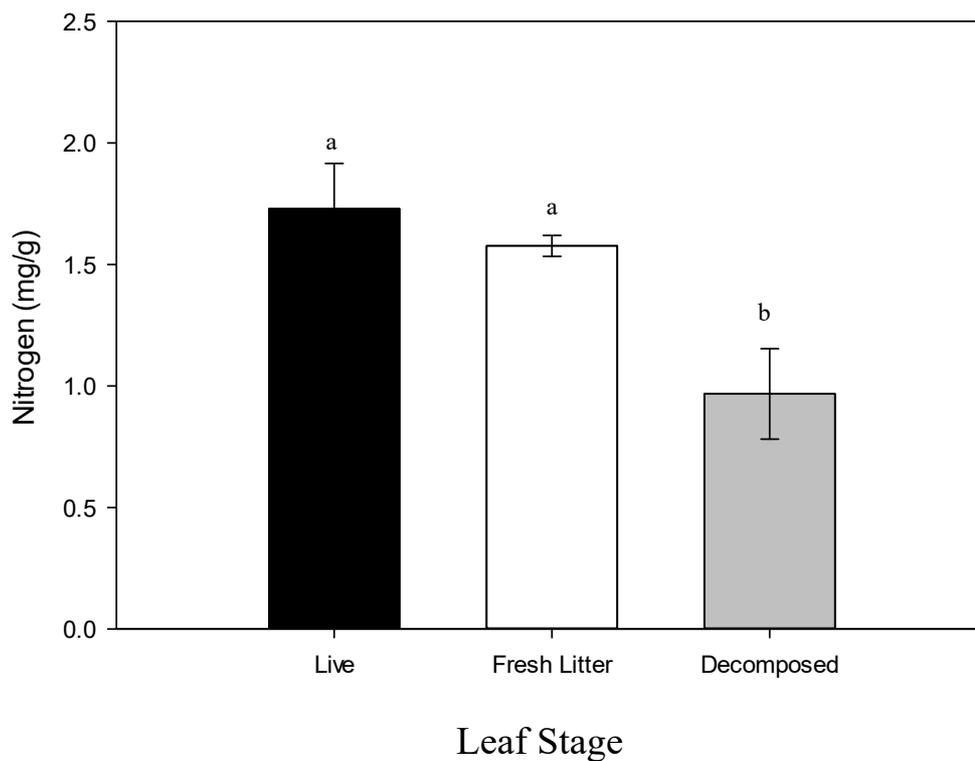


Figure 4. Nitrogen levels in live, freshly senesced, and 72-weeks decomposed giant cane leaves in southern Illinois. Means with dissimilar letters differ ($\alpha = 0.05$)

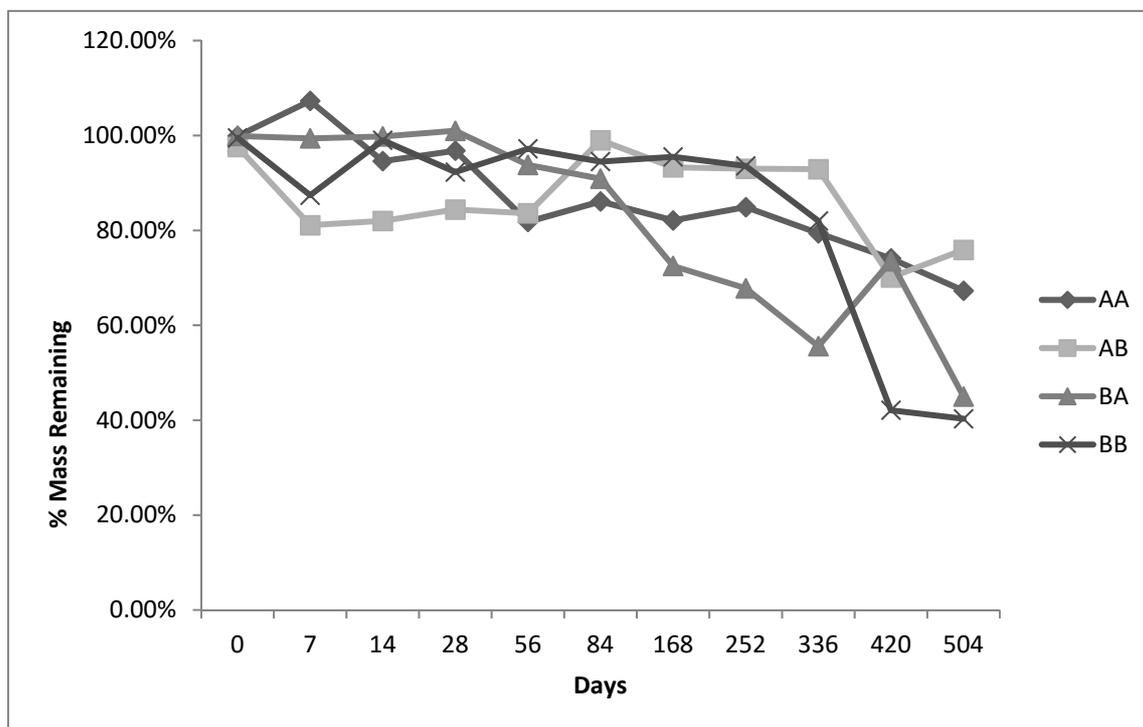


Figure 5. The percent cane litterfall mass remaining over time for the two sources at the two sites, November 2012 to February 2014. In the legend, the first letter indicates source location (Access/Buttonland or Bellrose), the second letter indicates decomposition location (Access/Buttonland or Bellrose)

4. Discussion

The average $400 \text{ g m}^{-2} \text{ yr}^{-1}$ of litter that fell in the canebrakes is lower than the average of $700 \text{ g m}^{-2} \text{ yr}^{-1}$ of litter Middleton and McKee (2004) determined falls in bottomland forests in southern Illinois. However, while canebrakes may deposit a lower annual load, leaves are dropped year round, as opposed to the predominantly fall deposition in the forests, providing a nutrient source throughout the year to both the soil and the adjacent stream.

Plants tend to transfer a higher fraction of leaf N to perennial tissues prior to leaf fall in N-limited ecosystems, particularly those composed of long-lived perennials, thereby making more efficient use of N (Chapin, 1980; Vitousek, 1982; Perez et al., 2003). The 8.1% RT of giant cane was much lower than the 47% found in evergreen shrubs and trees and the 54% found in deciduous shrubs and trees (Aerts, 1996). These data suggest that N is not limiting in the riparian cane system. Although not evaluated in this study, the canebrakes likely received significant amounts of N from the adjacent agricultural fields (corn/soybean rotation).

Due to environmental constraints such as water availability in soil, nutrient-resorption efficiency (e.g. percentage retranslocation) is not associated with nutrient status of leaves and site productivity; therefore, complementary NUE indices of species should be used (Aerts, 1996; Knops et al., 1997). Highly efficient plant species should have a higher C:N litterfall ratio, because they lose a smaller amount of N in relation to the quantity of fixed C (Chapin, 1980; Vitousek, 1982; Funk, 2007). Decomposers are relatively N limited and maintain N in their biomass when the ratio of available C:N is high ($> 25:1$). In these circumstances, decomposers may remove any available N from the soil solution and integrate it into their biomass. Contrarily, when the C:N ratio of substrate is low ($12-20:1$), decomposers are not N limited, and a net release of inorganic N to the soil solution follows (Vitousek, 1982). The canebrake's soil C:N ratio was $24.2:1$, thus neither N immobilization or mineralization dominated, though in a companion paper, it was determined that there was net mineralization occurring within the soil of the canebrakes (Nelson, 2014). As an NUE ratio, leaf C:N ratio could be associated with other physiological traits such as the degree of sclerophylly (fiber to protein ratio in leaves), the calcium:potassium ratio of leaves, and phosphorus concentration for woody species of southern temperate forests (Veneklaas, 1991; Perez et al., 2003). Some of these parameters may provide alternative explanations for differences in litter C:N ratios among canebrakes (Perez et al., 2003).

The N concentration in senesced leaves (resorption proficiency) is another proposed index (Killingbeck, 1996). Killingbeck (1996) stated that resorption is highly proficient in plants that have reduced N in their senescing leaves to concentrations below 0.7%. With a 1.58% resorption proficiency, giant cane would not be considered proficient. In addition, Vitousek (1982) stated that N-use efficiency of litter production varies as an inverse function of N availability and levels of 20 kg N ha⁻¹ yr⁻¹ are considered typical for sites with high atmospheric deposition. Though the annual deposition of 2.1 kg N ha⁻¹ yr⁻¹ indicates that there is ample N available, it is not necessarily indicative of high atmospheric deposition. It is more likely from excess N from fertilizer additions to the neighboring agricultural fields.

According to Berg and Meentemeyer (2002), when decay virtually ceases (at the limit value), more litter is left when the newly shed litter has higher N concentrations (lower C:N). There was no difference in initial C:N ratio between the two canebrakes used as leaf sources. Following 72 weeks decomposition, the cane leaves lost almost 50% N and 30% C. Gupta and Singh (1981) found that aboveground biomass of grasses decomposed at slower rates than that of broadleaves. This may be attributed to the higher N-use efficiency of most grasses which leads to a larger lignin:N ratio or because grass residue may consist of primarily cellulose, hemicellulose, and starches.

The mean k-rate of giant cane leaves of -0.0013 day⁻¹ was much slower than the rate reported for ash (0.0035 day⁻¹) or oak (0.0023 day⁻¹) (Adams & Angradi, 1995; Kuers & Simmons, 2005). Decomposition rates of leaf litter can be predicted by the C:N ratio (Taylor et al., 1989), by the lignin content (Meentemeyer, 1978), or by the lignin:N ratio (Melillo et al., 1982). Accordingly, studies have shown marked differences in decomposition rates among species (Adams & Angradi, 1995; Cornelissen, 1996; Kuers & Simmons, 2005). Berg and co-workers (Berg & Staaf, 1980; McLaugherty & Berg, 1987; Berg & Matzner, 1997; Berg et al., 2000) have shown that in the initial stages (0 to 3 mo) of leaf breakdown small soluble C molecules (starches) and amino acids, are lost first, leaving behind the more recalcitrant molecules (e.g. lignin) (Kuers & Simmons, 2005). This first phase of decomposition is rapid because these molecules are energy rich and easily metabolized by microorganisms. The first 90 days of cane leaf decomposition are also the most variable (Kuers & Simmons, 2005). The breakdown of lignin during the second stage of decomposition is much slower because lignin consists of very large and complex molecules (cross-linked phenyl-propane groups). A mass loss curve that resembles an exponential decay curve is the result of the initial rapid decay and the second slower phase (Kuers & Simmons, 2005). The decomposition of cane leaves was no exception, resulting in a classic exponential decay curve. After 500 days of decomposition, only one set of samples had leveled off, indicating that the remaining molecules were primarily the more recalcitrant. Leaves from black birch, yellow poplar, black cherry, and red maple all leveled off their mass loss at approximately 400 days in another decomposition study (Adams & Angradi, 1995).

Environmental factors affected decomposition of canebreak leaves as decomposition coefficients were different for the two canebrake sites, but not the two canebrake sources. Temperature and moisture are the abiotic influences that have the greatest effect on the rate of plant litter decay (Swift et al., 1979). The ideal temperature range for plant decomposition is 30 to 40 °C (Cornelissen, 1996; Paul, 2001). At these higher temperatures, the destruction of the plant cell wall components, particularly cellulose and lignin, greatly increases. However, there were no differences in soil temperature at the two sites, suggesting that the soil moisture differences greatly influenced the different rates of decomposition.

An exponential increase in decomposition rates can occur if there are favorable moisture conditions, during an increase in temperature. Soil moisture content shows a parabolic effect on decomposition rates during times of constant soil temperature, with a maximum rate at intermediate levels of moisture (Meentemeyer, 1978; Swift et al., 1979; Lee et al., 2014). High moisture content (VWC > 30%) restricts soil gas exchange leading to low oxygen concentrations and potentially anaerobic conditions (Meentemeyer, 1978; Lee et al., 2014). Low moisture content can limit microbial metabolism; however, many microorganisms can remain active at much lower soil water potentials than plants (Lee et al., 2014). Soil moisture ranged from 23% VWC to saturated (~60% VWC) for short periods of time in the current study.

The presence of moisture at field capacity in an ecosystem has its largest impact on the activity of soil microorganisms (Harre, 2014). A response to fluctuations in moisture regime in the decomposer community is more likely than in the plant community because even small precipitation events that only affect the uppermost soil layer can stimulate microbial activity (Vivanco & Austin, 2006; Harre, 2014). Drought conditions affect the activity of soil microorganisms and plant growth, causing stressed plants to produce litter that is of lesser quality (less nutrient-rich and less readily degradable) and is resistant to decomposition (Harre, 2014). There was a record breaking drought in the first summer of this decomposition study (~8 in deficit for May, June, July 2012, ~20 in deficit by the end of the year, IDNR, 2013), though the Access/Buttonland site was still periodically inundated. This difference in inundation frequency and length likely accounted for the soil moisture level differences between

the sites. With the assumption that no other resources are limiting, plants with sufficient access to water experience mineral uptake from soil that is less restrictive, resulting in tissue that is of higher quality (Harre, 2014). Therefore, decomposition rates increase along with rising temperatures and moisture levels (Meentemeyer, 1978; Harre, 2014). This was not the case in the present study; the site with the higher mean soil water content (Access/Buttonland) had the lower k-rate, while the site with the lower mean soil water content (Bellrose) had the higher k-rate. The Access/Buttonland site, the wetter of the two sites, likely relied on anaerobic decomposition, whereas the drier site (Bellrose) had aerobic conditions. Faster decomposition rates prior to litterfall could reduce the amount of available carbon throughout the year, adversely affecting the macroinvertebrate community by decreasing food resources (Fuell et al., 2013). Because giant cane may supply carbon to macroinvertebrates for a longer period of time and year round, it should be considered in multispecies riparian buffers.

5. Conclusion

Live leaves decrease 48% of N and 30% of C after falling and decomposing for 72 weeks, resulting in an input of nutrients into the soil beneath canebrakes. Giant cane canebrakes were not N limited as cane leaves had low resorption proficiency and NUP. Cane leaf decomposition rate was slower than oak and ash, and is dependent on soil moisture levels, perhaps due to the creation of anaerobic conditions. Therefore, soil moisture may determine the rate in which nutrients are added to the soil via decomposition. Though canebrakes may deposit a lower annual litter load when compared with deciduous trees, it is dropped year round, as opposed to the predominantly fall deposition in the forests, thereby supplying nutrients throughout the year to both the soil and the adjacent stream. Giant cane should be considered in multispecies riparian buffer creation since it has this potential to supply carbon and nitrogen to the soil and to macroinvertebrates in the streams for a longer period of time and year round.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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