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Seasonal Variation of Carbon and Nitrogen Emissions from Turfgrass

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Abstract

The role of turfgrasses in C and N cycling in the southeastern U.S. has not been well documented. The objectives of this research were to determine the characterization of chemical quality, clipping decomposition rates, and C and N release from warm- and cool-season turfgrasses. The study was conducted for 46 weeks in 2012 in Auburn, AL. Four warm season turfgrasses were used included (bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy], centipedegrass (*Eremochloa ophiuroides* (Munro) Hack), St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze), zoysiagrass (*Zoysia japonica* Steud.), and one cool season turfgrass (tall fescue (*Festuca arundinacea* Schreb)). Litter was placed into nylon bags at an oven dry rate of 3.6 Mg·ha^{-1}. Litter bags were retrieved after 0, 1, 2, 4, 8, 16, 24, 32, and 46 weeks, and analyzed for total C and N. A double exponential decay model was used to describe mass, C, and N loss. Results indicated that tall fescue decomposition occurred rapidly compared to warm season turfgrasses. Litter mass loss measured after 46 weeks was determined to be 61.7%, 73.7%, 72.2%, 86.8%, and 45.4% in bermudagrass, centipedegrass, St. Augustinegrass, tall fescue, and zoysiagrass respectively. Zoysiagrass litter had a higher lignin concentration, while tall fescue had the lowest lignin. Over 46 weeks' release of C was in the order: zoysiagrass > bermudagrass = centipedegrass = St. Augustinegrass > tall fescue, and release of N was in the order zoysiagrass > centipedegrass > bermudagrass = St. Augustinegrass > tall fescue. Our study concluded that, zosiagrass is a better choice for home lawns.

Keywords

Double-Exponential Decay Model, Turfgrasses, Fiber Content

1. Introduction

Understanding litter decomposition process in a given ecosystem is vital due to its effect on greenhouse gas concentration and biogeochemical cycling in terrestrial ecosystems. During decomposition, significant amounts of greenhouse gases, including CO_2, CH_4, and N_2O, are released [1]. Plants may also play an important role in C and nutrient cycling through the quality and quantity of their residues [2] [3] [4]. Also, the quality and type of litter material influence soil organic matter content [5].

Organic matter with higher C:N or lignin:N ratios decomposes slower, a function of lower N mineralization rates and increased N immobilization in microbial biomass [6]. Moreover, the ability of soil microorganisms to decompose and/or mineralize organic matter depends on the chemical structure of the C compounds [7]. Complex C compounds such as lignin can retard litter decomposition. Thus, the composition of plant residues, in particular C, N, and lignin concentrations, determines the rate and extent of decomposition of such residues. The concentration of lignin alone or the lignin:N content can be used as an indicator of decomposition rates [8] [9] [10].

Litter decomposition pattern of any material can be divided into two phases: an early and a later stage which are regulated by fractions different chemical of the material. The early phase is regulated by the labile fraction including sugars, starch, soluble and unprotected cellulose and hemicelluloses [11] and the later phase is regulated by the recalcitrant fraction including lignin and cellulose [12]. Thus, lignin and cellulose become dominant in the residue [13]. In some cases, the rate of decomposition approaches zero. This second portion is slowly decomposed, contributing to the development of soil organic matter.

There is limited research which examines decomposition rate of C and N dynamics in the long-term, non-tilled conditions in which warm and cool season's turfgrasses are grown. There is a need to evaluate C and N dynamics in warm and cool season's turfgrasses in the southeast United States. The objectives of this research were to determine the characterization of chemical quality, clipping decomposition rates, and C and N release from warm- and cool-season turfgrasses. That will solidify our understanding of different turfgrasses dynamics under current environment. In addition, it will reduce the emission of greenhouse gases through altering current turfgrass management by lowering fertilizer application rates and timing. A recent study summarized net C sequestration in home lawn turfgrasses across the U.S. included some warm-season turfgrasses, a large-scale survey from 16 sites across the U.S. [14]. However, there are no studies which examine decomposition as a function of specific warm-season turfgrass species, which have different growth patterns from cool-season turfgrasses. Thus, the objectives of this study were to assess mass loss and C and N decomposition rates from warm (bermudagrass, centipedegrass, St. Augustinegrass, and zoysiagrass) and cool (tall fescue) seasons turfgrass clippings and exploring the relationships between chemical leaf composition, particularly fiber content, and decomposition rates and C and N release under field conditions. The reason behind choosing these grasses is their extensive use in urban eco-systems in the southeastern U.S.

2. Materials and Methods

2.1. Site Description and Sampling

A field decomposition study was initiated in May 17, 2012 and conducted for 46 weeks (wk) at the Auburn University Turfgrass Research Unit (32.58˚N, 85.50˚W), Auburn, AL, USA, on a Marvyn loamy sand soil (fine-loamy, kaolinitic, thermic Typic Kanhapludult). The mean annual air and soil temperatures were 17˚C and 19˚C, respectively and the mean annual precipitation was 1233 mm (2011-2014, AWIS, 2014). Experiments were installed in 5 existing areas of common southeaster turfgrasses (4 warm season and 1 cool season): bermudagrass [*Cynodon dactylon* (L.) Pres. × *Cynodon transvaalensis* Burtt. Davy cv "Tifway"], Centipedegrass (*Eremochloa ophiuroides* Munro Hack cv "common"), St. Augustinegrass (*Stenotaphrum secundatum* Walter Kuntze cv "Floratam"), and zoysiagrass (*Zoysia japonica* Steud.) cv "Meyer", and cool season-tall fescue (*Festuca arundinacea* Schreb) cv "Rebel Exeda" were the selected species and cultivars. All of the turfgrass stands had been established for at least 5 years, and none were older than 7 years. All plots areas were no more than 300 m from each other. Swards were managed as lawn grasses, with the following mowing heights for each: bermudagrass and zoysiagrass (5.0 cm), tall fescue and St. Augustinegrass (7.6 cm) and centipedegrass (6.4 cm). Plots were mown either with a walk behind homeowner-type reel mower (Tru-Cut Mowers, Inc., 141 East 157th Street, Gardena, CA 90248) (bermudagrass and zoysiagrass) or with a homeowner riding rotary mower (Husqvarna Professional Products, Inc. Charlotte, NC 28269) (all other grasses), respectively. All plots were mown three days a week with clippings returned. Supplemental irrigation was provided in the absence of rainfall so that irrigation + precipitation equaled 2.5 cm·wk^{-1}. An on-site weather station was used to determine daily precipitation.

A litter bag decomposition method, often used in forestry, was employed for this study [15] [16]. For litter collection, all turfgrasses were harvested (3 m wide × 3 m long plot) at a height to remove no-more than 1/3 of uppermost green leaf tissue, for each respective mowing height. This ensured that scalping did not occur and that the majority of tissue was comprised of fresh leaf growth. All tissue was harvested using the mower that was used for plot maintenance, and clippings were collected in attached baskets. Four replicate plots of each turfgrass were harvested, and each was tracked through a litter bag as a replicate plot at each harvest time. Litter was transported immediately to the laboratory. Litter of each grass from each replicate was mixed separately, and weeds or other debris were removed. Litter was placed into nylon bags (ANKOM technology, Macedon, NY) measuring 10 × 20 cm with 50 to 60 μm openings at a rate of 30 g oven dry·bag^{-1} (3.6 Mg·ha^{-1}). The bags (total of 180; four replicates for each species) were incubated in the field, placed directly into the thatch layer (the area had been trimmed free of verdure) on the same grass plots from where it was harvested. The bags were anchored with sod staples at the edge of each bag, ensuring that the bags would not move due to wind or predators. Spacing between individual bags was 30 × 45 cm to prevent any interactions among bags. The total incubation period was 46 wk

(from May 17, 2012 to April 4, 2013). Four bags (replicates) of each species were retrieved at 1, 2, 4, 8, 16, 24, 32, and 46 wk. Fertilizer was withheld from experimental plots during the experiment.

Soil moisture and temperature were measured on a weekly basis using an auxiliary sensor (Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). The sensor was placed at a 5.0 cm depth in the soil, with soil moisture and temperature recorded at 5 minute intervals. Three sensors were placed in the bermudagrass plot area and results averaged for use for all grasses. Spot checks throughout the study period revealed that soil moisture and temperature was not substantially affected (over the entire study period) by grass species.

2.2. Carbon and Nitrogen Analyses

The four replicate bags from each grass species were retrieved from the field at 0, 1, 2, 4, 8, 16, 24, 32, and 46 wk. Retrieved bags were emptied into plastic containers and oven-dried at 55°C for 72 h and weighed for dry-matter determination. Litter was ground to pass a 1 mm-sieve and analyzed for total C and N using LECO TruSpec CN analyzer (Leco Corp, St. Joseph, MI). All data were converted to an ash-free dry weight basis by ashing 1 g of sample in a muffle furnace at 450°C for 16 hours [17]. In addition, C:N ratios were calculated.

2.3. Initial Fiber Analysis

Initial values of lignin concentration in leaf litter were assessed by the acid-detergent digestion technique [18]. The acid detergent fiber technique measures cellulose, lignin, and ash, and represents the insoluble components of cell walls. Acid detergent lignin (ADL) is an estimate of the lignin content. Neutral detergent fiber (NDF) comprises the insoluble components of cell walls (cellulose, hemicellulose, and lignin). Acid detergent fiber (ADF) is a measure of cellulose and lignin [19].

2.4. Decay Model

A double, four-parameter exponential decay model (Equation (1)) [13] [20], simulating decomposers and substrates (labile and the recalcitrant constants) dynamics in grasslands, was used to describe the decay pattern.

$$Y = Ae^{-bx} + Ce^{-dx} \qquad (1)$$

where Y = remaining mass (normalized %),

A = the labile portion,

C = the recalcitrant portion,

b and d are the labile and the recalcitrant constants, respectively, and

x = time in weeks.

2.5. Data Analysis

Means, standard errors, and statistical variations of treatments were determined using mixed models procedures [21]. Least squares estimates for nonlinear models were de-

termined using four parameter double exponential decay models [22]. Double exponential decay models were employed as the basis for comparison of mass, N, and C loss between dates among all grasses. SigmPlot 12.1, Non-Linear Regression, was used to identify correlations (r) among variables [22].

3. Results and Discussion

3.1. Initial Fiber Analysis

The initial fiber composition of harvested clippings had significant variation among the five turfgrass species (Table 1). For example, St. Augustinegrass clippings were significantly higher in acid detergent fiber (cellulose + lignin) (ADF) and ash contents than bermudagrass, centipedegrass, tall fescue, and zoysiagrass. Zoysiagrass litter had significantly higher lignin concentration, 6% ± 0.3% (mean ± SE), while tall fescue had the lowest content, at 3% ± 0.3%. The initial harvest of bermudagrass clippings had significantly higher neutral detergent fiber (hemicellulose + cellulose + lignin) (NDF) than found in other grasses, measuring 85% ± 0.3%. In contrast, tall fescue had the lowest NDF, measured at 63% ± 1.1%. Fiber contents play an important role in accelerating and/or suppressing decomposition processes.

The litter exhibiting higher initial lignin content had slower decomposition rates. For example, decomposition of *Quercus dealbata* (6% lignin) litter had slower decomposition than *Quercus fenestrata* (4% lignin) [23]. In other work, concentration of the lignin fraction increased as decomposition proceeded [24], and litter was enriched with lignin [25]. In later stages of decomposition, recalcitrant substances become more dominant in the residue, and in some cases the rate of decomposition approaches zero.

3.2. Remaining Mass

In all cases, the decay models were significant ($P < 0.0001$) with reasonably high adjusted R^2 values (Table 2). All data were expressed on a normalized basis (percent remaining) (Figure 1). Figure 1 indicates that the litter mass loss measured after 46 weeks was estimated at 45.4%, 61.7%, 73.7%, 72.2%, and 86.8% in zoysiagrass, bermudagrass,

Table 1. Initial turfgrasses clipping contents (g·kg⁻¹) and the carbon and nitrogen (%) released after 46 weeks of field incubation

Grasses	Initial contents (g·kg⁻¹)					Released contents (%)	
	NDF	ADF	ADL	Carbon	Nitrogen	Carbon	Nitrogen
Bermuda	849.60a	347.61b	49.00b	396a	23.0b	63.3c	53.6b
Centipede	731.66d	356.37b	39.43c	421a	14.5c	66.2c	37.3c
St. Augustine	800.85c	424.65a	48.80b	340b	14.7c	82.1b	85.8a
Tall fescue	629.34e	296.17c	31.33c	412a	40.0a	87.9a	87.7a
Zoysia	824.54b	371.19d	59.61a	429a	14.6c	45.1d	31.5c

Means in the same column with the same letter are not significantly different at $\alpha \leq 0.05$; NDF = Natural Detergent Fiber contains hemicellulose + cellulose + lignin (approximately total cell wall), ADF = Acid Detergent Fiber comprise cellulose + lignin, and ADL = Acid Detergent Lignin.
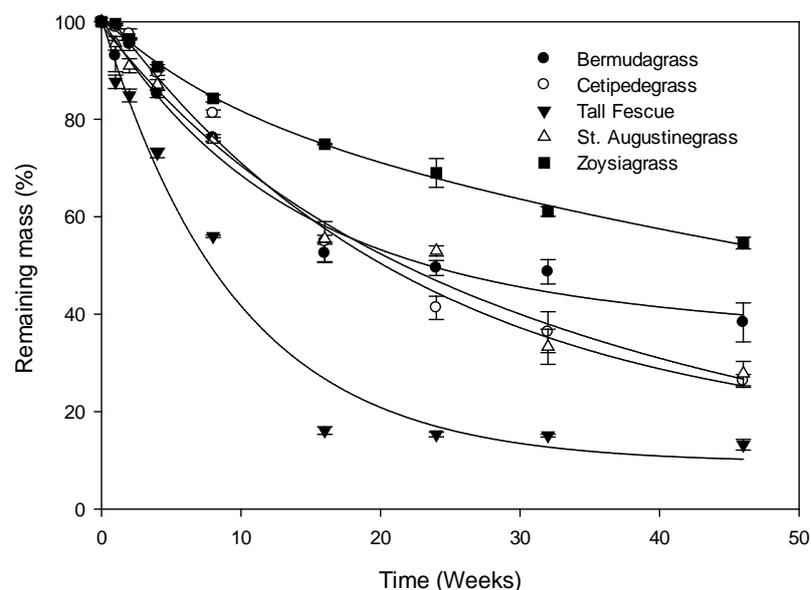
Figure 1. Mass loss from turfgrass clippings over time, Auburn University Turfgrass Research Unit, 2012-2013. Lines represent fitted curves for each grass describing decay pattern over time. Error bars represent standard error about the mean.

Table 2. Double exponential decay equations regressed on time (weeks) for mass, C, and N-loss from turfgrass incubated in litter bags under field conditions. Double exponential decay equations are in the form of $Y = Ae^{-bx} + Ce^{-dx}$, where Y = remaining mass (normalized %), A = the labile portion, C = the portion, b and d are the labile and the recalcitrant constants, respectively, and x = time in weeks.

Turfgrass	Equation	P > F[†]	R^2_{adj}	Syx[‡]
Mass				
Bermudagrass	$Y = 56.22e^{-0.08x} + 44.33e^{-0.003x}$	<0.0001	0.99	1.14
Centipedegrass	$Y = 89.54e^{-0.05x} + 13.75e^{-8.28E-19x}$	<0.0001	0.97	5.24
St. Augustinegrass	$Y = 19.43e^{-0.09x} + 80.02e^{-0.02x}$	<0.0001	0.96	4.69
Tall Fescue	$Y = 91.25e^{-0.11x} + 9.47e^{-8.12E-19x}$	<0.0001	0.96	4.69
Zoysiagrass	$Y = 16.87e^{-0.12x} + 84.14e^{-0.01x}$	<0.0001	0.96	4.69
Carbon				
Bermudagrass	$Y = 47.61e^{-0.11x} + 52.13e^{-0.01x}$	<0.0001	0.99	2.46
Centipedegrass	$Y = 87.82e^{-0.04x} + 13.72e^{-4.93E-18x}$	<0.0001	0.98	3.14
St. Augustinegrass	$Y = 87.67e^{-0.04x} + 5.21e^{-9.92E-18x}$	<0.0001	0.96	4.69
Tall Fescue	$Y = 89.91e^{-0.11x} + 9.32e^{-1.08E-17x}$	<0.0001	0.97	6.04
Zoysiagrass	$Y = 11.17e^{-0.28x} + 90.14e^{-0.01x}$	<0.0001	0.98	2.06
Nitrogen				
Bermudagrass	$Y = 30.15e^{-0.28x} + 69.82e^{-0.01x}$	<0.0001	0.98	2.97
Centipedegrass	$Y = 8.64e^{-0.89x} + 91.36e^{-0.01x}$	<0.0001	0.97	2.54
St. Augustinegrass	$Y = 28.58e^{-0.56x} + 72.31e^{-0.02x}$	0.0002	0.95	4.70
Tall Fescue	$Y = 72.26e^{-0.21x} + 22.68e^{-0.01x}$	0.0001	0.96	5.71
Zoysiagrass	$Y = 20.49e^{-0.16x} + 79.94e^{-3.62E-19x}$	0.0290	0.69	4.95

[†]Significance of fit. [‡]Standard error of the estimate.

centipedegrass, St. Augustinegrass, and tall fescue, respectively. However, zoysiagrass had very slow decomposition, with only 25% loss from an initial equivalent of 360 g·m^{-2} to 270 g·m^{-2}. Similar results were observed by [26]. They found that, in 16 weeks' decomposition study, combinations of litters of cool-season turfgrass clippings of a bluegrass-ryegrass-red fescue mixture decomposed rapidly during the first 4 months, with a value of ≈70% of total mass [26]. The faster decomposition rate of tall fescue can be partially explained by the lower initial ADF content.

The labile decay constant of zoysiagrass residue value (0.12) was 2.6 times greater than that of centipede grass (0.05) but closer to that of tall fescue (0.10). The effects of grass species on decay of recalcitrant portions were more distinct. The recalcitrant decay constant of zoysiagrass (0.0096) was greater than that of centipedegrass (8.28 × 10^{-19}) or tall fescue (8.12 × 10^{-19}). Rapid decay of turfgrass tissues are typically related to warmer soil temperatures (**Figure 2**) [27]-[32] and adequate moisture contents [32] [33] [34], which stimulate both soil microbial activity and arthropods involved in decomposition processes.

Labile portions of warm-season turfgrass litter increased from 16.9% to 89.5%, and recalcitrant portions decreased from 84.1% to 13.8% under zoysiagrass and centipedegrass, respectively (**Table 2**). In contrast, tall fescue (cool-season grass) had a labile portion of 91.2%, and a recalcitrant portion of 9.5%. Such contents could significantly influence decomposition processes by acceleration and/or suppression. Thus, increasing the labile fraction is associated with decreasing the recalcitrant portion and will increase the decomposition rate.

3.3. Carbon Release from Turfgrass Clippings

All C data were expressed on a normalized basis (percent remaining) (**Figure 3**). In all cases, the regression models were significant ($P < 0.0001$) with reasonably high adjusted
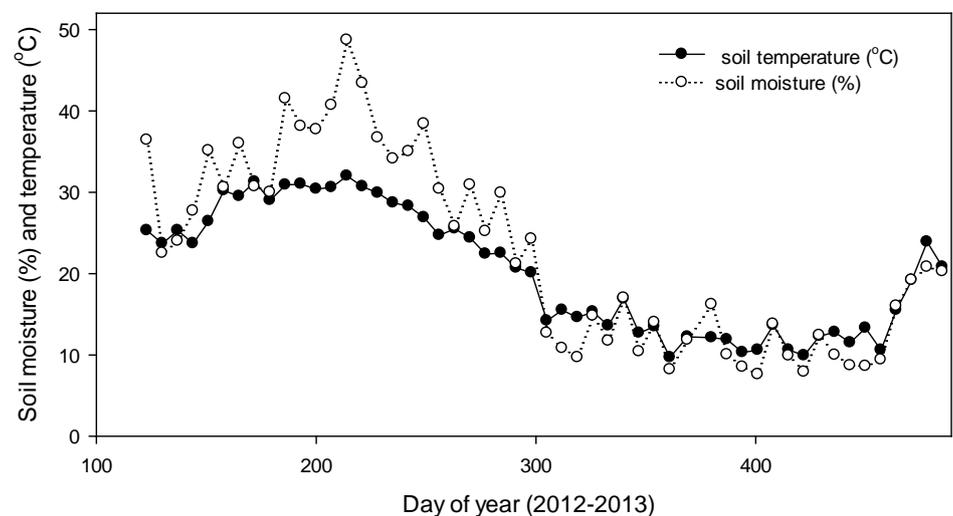
Figure 2. Measured soil temperature and moisture contents at 5 cm soil depth during decomposition study at the Auburn University Turfgrass Research Unit, 2012-2013.
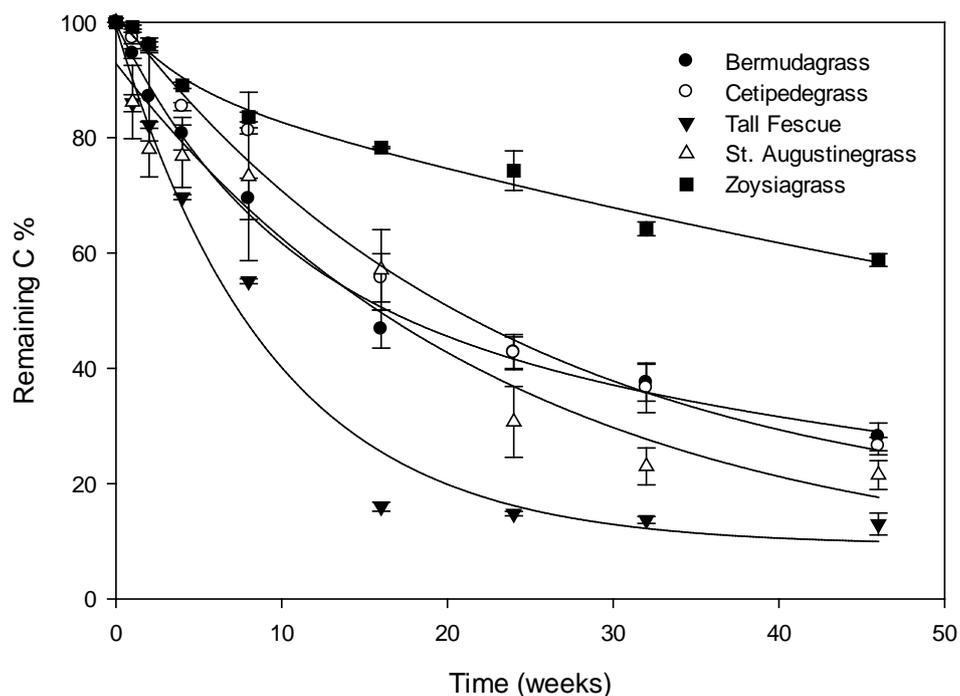
Figure 3. Carbon loss from turfgrass clippings, Auburn University Turfgrass Research Unit, 2012-2013. Lines represent fitted curves for each grass describing decay pattern over time. Error bars represent standard error about the mean.

R^2 values (Table 2). As with the mass models, the C rate constant values c and d were larger for zoysiagrass residue than for centipedegrass, St. Augustinegrass, and tall fescue residues combined. Initial C concentrations of turfgrasses differed slightly, from 42.8% in zoysiagrass, compared to 40.6, 42.2, 41.7, and 39.1 under bermudagrass, centipedegrass, tall fescue, and St. Augustinegrass, respectively. After 16 weeks of field incubation, zoysiagrass had lost only 21.7% of C content, while tall fescue lost 84%. Carbon loss models were comparable to mass loss. This loss was attributed to mass lost through microbial respiration of C (as CO_2) to the atmosphere [35]. Tall fescue C decreased faster during warmer temperatures. The labile decay constant of tall fescue value (0.11) (Table 2) was greater than that of centipede and St. Augustine grasses combined. The recalcitrant decay constant of tall fescue (1.07×10^{-17}) was nearly two times greater than centipedegrass (4.93×10^{-18}) and more than 100 times lower than zoysiagrass (0.01). The labile C portion of centipedegrass, tall fescue, and St. Augustinegrass was greater than 87%, and the recalcitrant portion of all these grasses was lower than 14%. In comparison, zoysiagrass had approximately 11% labile and 90% recalcitrant fractions. This may be the reason behind resistance to decay.

The time to decompose the turfgrass clipping varied with species. At 24 weeks, tall fescue C had declined by 85.2%, while zoysiagrass decreased by 25.7%. These differences may be caused by the chemical fiber structure such as NDF in the clippings. After 46 weeks, there were significant differences in C among turfgrass clippings with exception of bermudagrass and centipedegrass.

Carbon concentrations were negatively correlated with sampling time in bermudagrass (r = 0.88**) and St. Augustinegrass (r = 0.72*), however, correlation was positive for centipedegrass (r = 0.85**), tall fescue (r = 0.91***), and zoysiagrass (r = 0.75*) (**Figure 4**). The increase or decrease of C over time could be related to microbial biomass decomposition causing C release from soil or immobilization by microbial population.
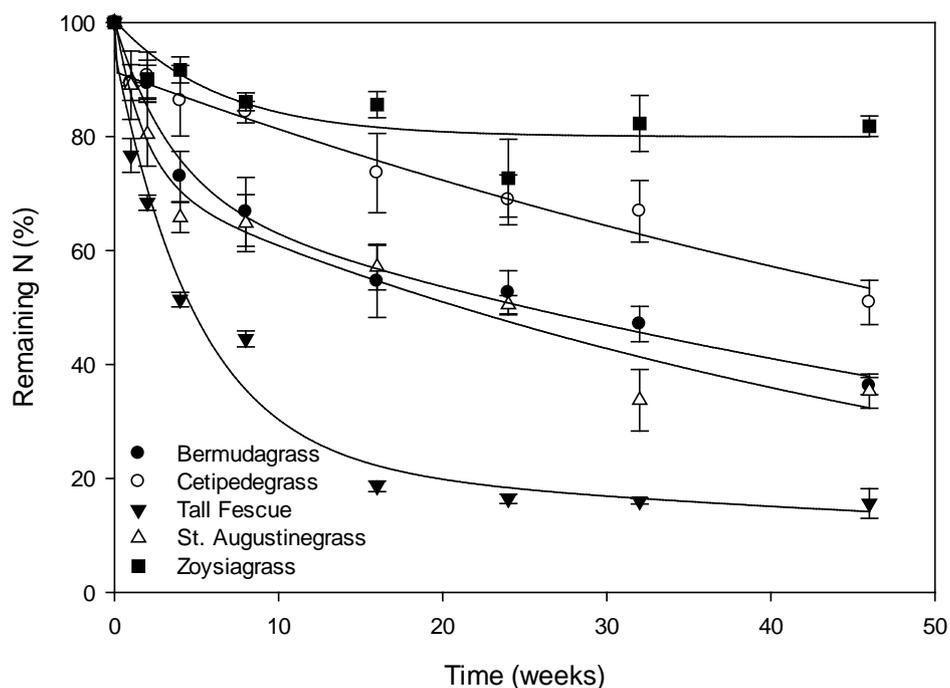
3.4. Nitrogen Release from Turfgrass Clippings

Nitrogen data fit to double exponential decay models on a normalized basis. Adjusted R^2 value for that model was high, with the exception of that calculated for zoysiagrass (0.69). This was likely due to the small amount of N and fast release of labile N for zoysiagrass. Initial N concentrations in turfgrasses were low, with a N concentration of 14.5 g·N·kg^{-1} in centipedegrass, compared to 14.7 and 14.6 g·kg^{-1} in St. Augustinegrass and zoysiagrass, respectively. Tall fescue had a higher N concentration (40 g·kg^{-1}, **Table 3**), followed by bermudagrass (23 g·kg^{-1}). After 24 weeks of field incubation, zoysiagrass lost 17.3% of N content, compared to 47.4%, 31.1%, 49.5%, and 83.6% loss by bermudagrass, centipedegrass, St. Augustinegrass, and tall fescue, respectively (**Figure 5**).

The labile decay constant of centipedegrass (0.88; **Table 2**) was greater than that of bermudagrass, tall fescue, and zoysiagrass combined. The recalcitrant decay constant of centipede (0.01) was not greater than that of tall fescue (0.01) and more than 100 times greater than zoysiagrass (3.62×10^{-19}). The higher the constant the faster the decomposition.
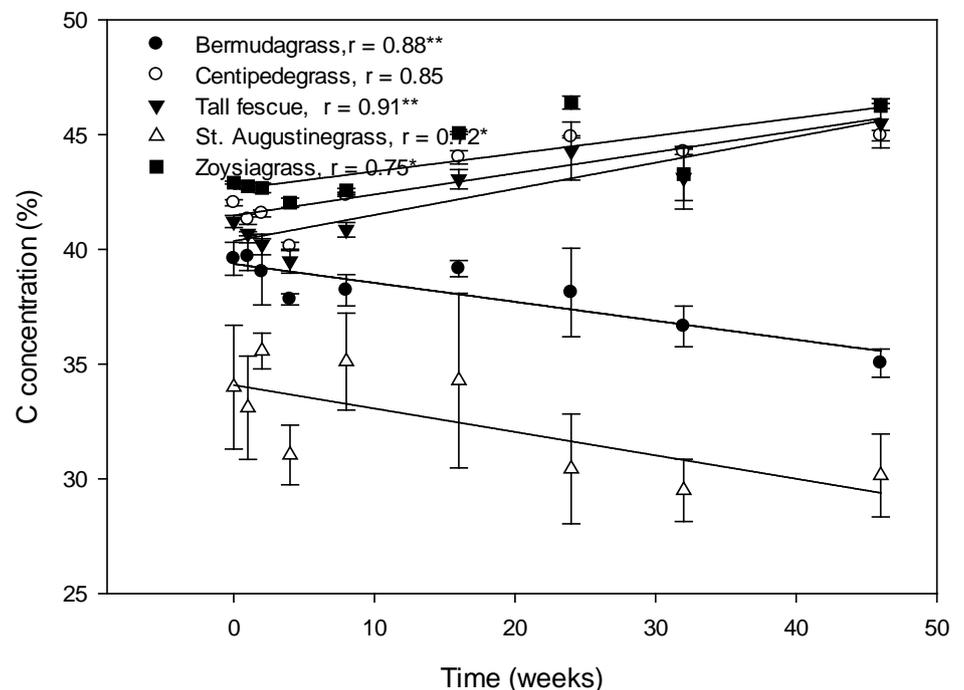
Figure 4. Relationship between C concentration (%) and time of sampling for turfgrass clippings, Auburn University Turfgrass Research Unit, 2012-2013. Lines represent fitted curves for C% content of each grass.

Figure 5. Nitrogen loss from turfgrass clippings, Auburn University Turfgrass Research Unit, 2012-2013. Lines represent fitted curves for each grass describing decay pattern over time. Error bars represent standard error about the mean.

Table 3. Carbon: nitrogenratios ± S.E of turfgrasses at each sampling period.

Week	Bermuda grass	Centipede grass	Tall fescue	St. Augustine grass	Zoysia grass
0	18.6 ± 0.7	28.7 ± 1.0	10.3 ± 0.1	22.4 ± 1.3	29.3 ± 0.7
1	19.4 ± 0.3	29.1 ± 0.8	11.6 ± 0.3	22.2 ± 2.5	28.3 ± 0.5
2	19.9 ± 0.4	30.5 ± 1.3	12.4 ± 0.2	23.2 ± 0.9	30.5 ± 0.6
4	20.6 ± 0.5	28.7 ± 1.4	14.0 ± 0.4	24.7 ± 1.0	28.6 ± 1.1
8	19.4 ± 0.3	26.5 ± 0.5	12.8 ± 0.5	18.3 ± 5.5	28.3 ± 0.6
16	16.1 ± 0.9	22.1 ± 0.5	8.9 ± 0.1	21.7 ± 1.7	26.8 ± 0.5
24	15.1 ± 0.4	17.8 ± 0.7	9.4 ± 0.4	16.4 ± 0.8	26.1 ± 1.1
32	14.7 ± 0.2	15.5 ± 0.4	8.8 ± 0.4	14.7 ± 0.3	23.6 ± 0.4
46	14.3 ± 0.5	15.0 ± 0.2	9.6 ± 0.6	13.4 ± 0.3	20.5 ± 0.3

The labile portion of tall fescue was 72%, and the recalcitrant portion was 23% (**Table 2**). McCurdy *et al*. [36] found similar results, with a labile fraction of 80% and a recalcitrant portion of 25% in white clover litter incubated under field conditions. In contrast, centipedegrass had a low labile fraction (9%) and a high recalcitrant fraction (91%), indicating slower decomposition rate.

After 46 weeks, statistical analysis shows significant differences in the remaining and released N concentration among turfgrasses. For example, zoysiagrass represented the lowest value of released N with a value of 31.5% of total N compared to 87.7% of released N from tall fescue (**Table 3**).

Although the biomass of all grasses are decreasing over time, the N concentration is increasing (**Figure 6**). Nitrogen concentrations were significantly correlated with sampling time in bermudagrass (r = 0.86**), centipedegrass (r = 0.98**), tall fescue (r = 0.77*), St. Augustinegrass (r = 0.94**), and zoysiagrass (r = 0.96**) (**Figure 6**). A linear relationship between percent remaining biomass and nutrient concentration has been noted in other plants [37] [38] [39]. Changes in mass indicate loss of organic C during respiration, while changes in N concentration indicate changes in microbial biomass [37].

Previous studies reported similar results under different ecosystems, included five exotic plant species such as *Acacia auriculiformis, Cassia siamea, Casuarina equisetifolia, Eucalyptus hybrid* and *Grevillea pteridifolia* growing on coal mine spoil [40], in pine needles [41], woodland ecosystems [42] and a mixture of herbaceous plants in Mediterranean subtropical agro-ecosystems [43]. This N increase could be related to lignin compounds. Fioretto *et al.* [44] reported that most N concentration in litter is bonded with lignin compounds, and N release will take place when lignin decomposition happens. They also suggested that lignin structure covers cell wall proteins, which protect them from microbial degradation [44].

3.5. Carbon/Nitrogen Ratio

The nature of warm-season turfgrass decomposition is different than that of cool-season turfgrass [45]. Warm-season turfgrass contains a relatively high concentration of C,
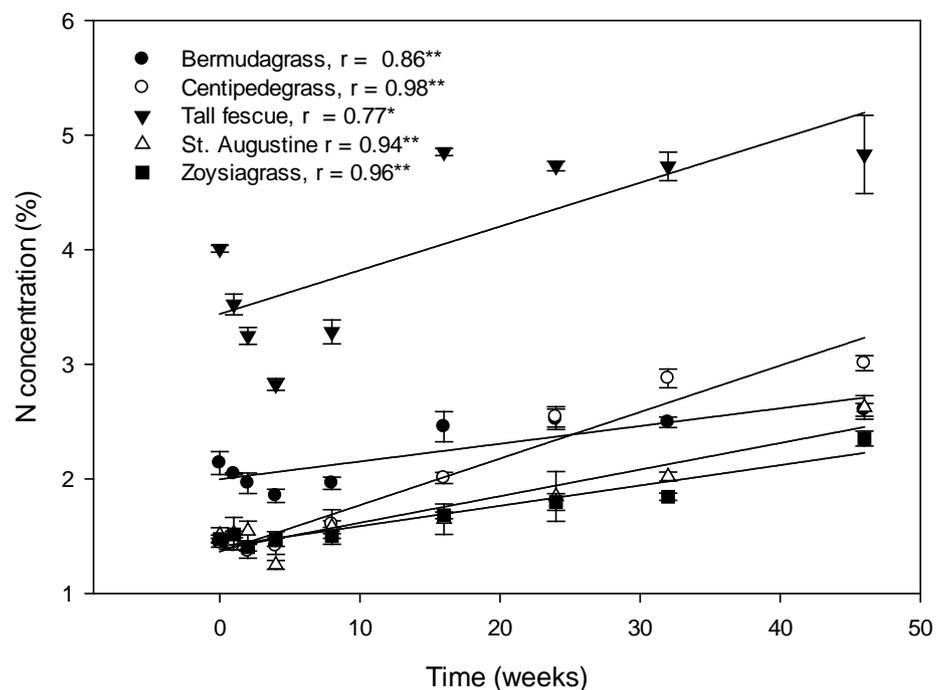
Figure 6. Relationship between N concentration (%) and time of sampling for turfgrass clippings, Auburn University Turfgrass Research Unit, 2012-2013. Lines represent fitted curves for N% content of each grass over time.

allowing for slower initial decay [46]. Typically, initial C:N ratios were 18.6 ± 0.7, 28.7 ± 1.0, 10.3 ± 0.1, 22.4 ± 1.3 and 29.3 ± 0.7 for bermudagrass, centipedegrass, tall fescue, St. Augustinegrass, and zoysiagrass, respectively (Table 3). Table 3 illustrates C:N ratios of the turfgrass clippings. C:N ratios are typically used to describe a residue's propensity to immobilize or mineralize soil inorganic N [47]. The critical C:N ratio for immobilization/mineralization is between 19 and 30 [37] [48] [49]. Thus, the C:N ratio plays a major role on N dynamics in soil [50] [51].

During the first 4 weeks the C:N ratio increased for all turfgrass species but does not limit the activity of decomposer organisms (C:N ratio < 30:1, [26]. For example, the C:N ratios of centipedegrass and zoysiagrass had increases for the first 2 weeks indicating a faster decay. Thereafter the C:N ratio declined indicating stabilization of decay process. After 46 week the C:N ratio of tall fescue was 9.6, compared to 13.4, 14.3, 15.0, and 20.5 for St. Augustinegrass, bermudagrass, centipedegrass, and zoysiagrass, respectively. Throughout the study tall fescue had the lowest C:N ratio, averaging 10.9, indicating that clippings from this turfgrass would be a long-term N contributor. Other grasses had higher initial C:N ratios, and they could be responsible for soil N immobilization. For example, in the first 8 weeks average C:N ratios in centipedegrass, St. Augustinegrass and zoysiagrass were 28.7, 22.2 and 29.0, respectively. Similar conclusions were drawn by [26].

3.6. Lignin/Nitrogen Ratio

Warm season turfgrasses had higher lignin:N ratio contents than tall fescue. Initial lignin:N ratios were: 0.33, 0.27, 0.99, 0.40 and 0.08 for bermudagrass, centipedegrass, St. Augustinegrass, zoysiagrass, and tall fescue, respectively. Lignin:N ratios of warm season turfgrasses are comparable with that measured for sub-tropical forest ecosystem litter [23]. The low lignin of tall fescue helps to explain the faster decomposition of tall fescue clippings compared to other turfgrasses. In addition to that, adequate soil moisture contents played a major role in decomposition process by increasing or decreasing the process. That may be related to its effect on soil microorganisms and arthropods. Similar conclusions were drawn by [8] [9] [10] [52].

4. Conclusion

Our research demonstrates important aspects of warm and cool season turfgrass decomposition, mainly that tall fescue is comprised mostly of a quickly decaying labile fraction. Labile and recalcitrant decomposable C and N are important for short- and long-term effects on available N concentration in soil. Modeling warm- and cool-season turfgrass decomposition may enable turfgrass researchers and professionals to more accurately choose the best grass for home owners. Our study concluded that, zoysiagrass may be a better choice for lower N fertilization requirements and higher C accumulation in soils followed by bermudagrass, centipedegrass, St. Augustinegrass, and tall fescue. In addition, our study clearly shows that the decomposition of different turfgrass clippings presents rapidly released N within the thatch layer of turfgrass.

Thus, a portion of that N will be available to that turfgrass during growing season. Then, N fertilization should be reduced when clippings are returned to turfgrass lawns. Moreover, differences in clipping C released under our study can be assumed that a portion of remaining C in the thatch layer could be important factor in soil C sequestration under southeastern U.S. turfgrass species and reduce climate change effect on turfed lawns [53]. However, further research is needed to determine the effect of returned clipping on the soil C and N balance of soil profile under different managements.

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