Received: 20 April 2022 | Accepted: 10 August 2022 | Published online: 30 November 2022

DOI: 10.1002/agj2.21193

Agronomy Journal

ORIGINAL ARTICLE

Crop Economics, Production, and Management

Residue management and genotype effect on sunn hemp organic matter and nitrogen decomposition

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Assigned to Associate Editor Bhupinder Singh.

Funding information
Fulbright-ICETEX Pasaporte a la Ciencia; Florida Agricultural Experiment Station; Tropical Seeds LLC

Abstract

Sunn hemp (*Crotalaria juncea* L.) is a warm-season legume often used as a cover crop; however, there is limited information about nutrient cycling of sunn hemp residue. The objective of this study was to evaluate the effect of sunn hemp genotype and residue management on plant characteristics, decomposition, and suppression of *Fusarium*, *Pythium*, *Sclerotinia*, and *Sclerotium* microbe species. Two field experiments were conducted in Ona, FL. In Experiment 1, treatments were the split-plot arrangement of three sunn hemp genotypes (Ubon, Blue Leaf, and 'Tropic Sun'; main plot) and two biomass managements (removal or leaving the biomass on the field; subplot), distributed in a randomized complete block design. There was a greater biomass accumulation in 2019, but with no differences among genotypes (mean = 4,431 kg DM ha^{-1}). Blue Leaf had greater N concentration than Ubon (23 vs. 19 g kg^{-1}) and greater suppression of the *Phytium* populations than Ubon and Tropic sun in 2019 (0.9 vs. 2.0 colony forming unit g $soil^{-1}$). In Experiment 2, the litter bag technique was used to estimate biomass and N decomposition. Treatments were the factorial arrangement of three genotypes and two residue management strategies (incorporated into the soil or placed on the soil surface). Sunn hemp biomass incorporation enhanced organic matter disappearance and N mineralization rate but leaving sunn hemp on the soil surface may result in a steadier N supply for the subsequent crop.

1 | INTRODUCTION

Sunn hemp is a fast-growing warm-season legume with relative high biomass and N accumulation. Sunn hemp was introduced in the United States in the 1930s to supply the fiber demand generated during the Second World War (Cook & White, 1996). Currently, it is used worldwide as a cover crop, green manure, or forage (Akbar & Ahmed, 2006; Bearden, 2018; Wanapat et al., 2021). The use of sunn hemp in crop rotation has been effective to increase the production of tomato (*Solanum lycopersicum* L.) (Q. Wang et al., 2009), strawberry (*Fragaria* × *ananassa* Duchesne) (Li et al., 2021), and sweet corn (*Zea mays* L.) (Cherr et al., 2006b) in Florida.

Abbreviations: CFU, colony forming unit; IVDOM, in vitro digestible organic matter; OM, organic matter.

Few sunn hemp genotypes are commercially available in Florida. Jaramillo et al. (2020) evaluated three sunn hemp genotypes in North Florida and observed that Tropic Sun (referred to in the publication as Crescent Sun) and Blue Leaf had greater nutritive value and atmospheric biological N_2 fixation than Ubon. However, Ubon has been more attractive to producers due to lower seed costs. Therefore, further studies are required to evaluate the nutrient contribution and soil benefits of the different sunn hemp genotypes.

Sunn hemp has been primarily used as cover crop where biomass is left on the field to benefit the subsequent crop (Q. Wang et al., 2003; Weiler et al., 2019; Young-Mathews, 2017). However, there is an increasing interest in using sunn hemp as forage, where biomass is harvested as hay or silage to feed livestock (Garzon et al., 2021). It is expected that the removal of the biomass would decrease the benefits of sunn hemp on nutrient cycling and soil health; however, there is limited information in the literature about the potential consequences of this management practice.

Previous studies reported rapid decomposition of labile components of sunn hemp residues such as sugars, and low molecular weight phenols, particularly during the first 50 d of incubation (Cherr et al., 2006b; Lynch et al., 2016; Stallings et al., 2017). Research has also indicated that a greater proportion of soluble components in the cover crop often results in faster release of nutrients to the soil (Coleman et al., 2004). Baitsaid et al. (2018) concluded that incorporating plant residues into the soil promotes greater decomposition rate compared with surface application. Similarly, the warm and moist climatic conditions in Florida and predominant coarse-textured soils favors decomposition of plant organic materials (Brady & Weil, 2017).

Sunn hemp is effective in suppressing root-knot nematodes [*Meloidogyne incognita* (Kofold and White)] in the soil, by acting as a nonhost or a poor host, producing allelochemicals that are toxic or inhibitory, and trapping the nematodes (K. Wang et al., 2002). However, it is not known that using sunn hemp as cover crop could suppress common pathogens of horticultural crops. Agricultural and horticultural crops in Florida are affected by the specific microbial taxa that favor warm temperature and high humidity (Savary et al., 2012), including species of *Fusarium*, *Pythium*, and *Sclerotinia*. *Fusarium* species are widely distributed throughout the world and are usually harmless in healthy soil. However, crop management can favor some infectious species (e.g., *Fusarium oxysporum*) without strong competitors, causing "fusarium wilt" in sensitive plants, such as tomato, onion (*Allium cepa* L.), or strawberry, among others (Vallad et al., 2016). *Pythium* infectious species can affect a wide range of plant hosts and decrease production in sensitive crops (Allen et al., 2004; Jarvis, 1992). For example, *Pythium* spp. cause the common rot of plant roots, also named "cottony blight". *Sclerotinia* causes "white mold" disease in tomato, cauliflower (*Brassica oleracea* L.), carrot (*Daucus carota* L.), and lettuce (*Lactuca sativa* L.), among other crops. White mold causes water-soaked lesions in leaves and generates rot of stems and fruits (Paret et al., 2018). *Sclerotium* causes "southern blight", which seriously affects groundnut (*Arachis hypogea* L.) production in southern Florida, together with tomato, eggplant (*Solanum melongela* L.), melon (*Cucumis melo* L.), and cereals (Xie & Vallad, 2016).

Core Ideas

- Sunn hemp genotypes differed in chemical composition.
- The genotype Blue Leaf most effectively suppressed Pythium populations in the soil.
- Sunn hemp residue management (surface vs. incorporated) affected decomposition.
- Genotypes did not differ in residue organic matter and N decomposition.

Sunn hemp produces pyrrolizidine alkaloids and nonprotein amino acids as secondary metabolites. Some of these compounds exert control over some weeds, and bacterial, fungal, and nematode populations in the soil (Garzon et al., 2021; Goyal, 2013; Mosjidis et al., 2012). Alkaloid accumulation occurs mainly on seeds (Price et al., 2012), but small concentrations in the leaves also allow pathogen control through litter decomposition in the soil (K. Wang et al., 2004).

Finally, cultivating sunn hemp in the same area for consecutive years had beneficial effects for subsequent crops, such as increased productivity in corn and bean plants (*Phaseolus vulgaris* L.) (Fischler et al., 1999) and rice (*Oryza sativa* L.) (Tripathi et al., 2009). The residual activity is also effective in suppressing nematodes if sunn hemp is established alternately with other cash crops (K. Wang et al., 2002) and this characteristic could also exert control over other potentially pathogenic microbial populations in soil. However, the effects of subsequent crops of sunn hemp on plant and soil microorganisms are not fully explored.

The hypothesis of this study is that different sunn hemp management practices affect biomass accumulation, nutritive value, decomposition rate and potentially pathogenic microbial population in the soil. The objective of this study was to evaluate the effect of sunn hemp genotype and biomass management on biomass accumulation, nutrient cycling, and potential soil pathogenic microbial species suppression.

2 | MATERIALS AND METHODS

2.1 | Experimental site

The study was conducted at the University of Florida, Range Cattle Research and Education Center (RCREC) located in Ona (Florida) (27°23′18″ N; 81°56′38″ W, 24 m asl) from April to December 2018 and 2019. Predominant soil is a Smyrna sand (sandy, siliceous, hyperthermic Aeric Alaquod). Selected initial soil chemical properties include pH (in water) of 6.5 and Mehlich-3 P, K, Mg, and Ca concentrations (0-to-15-cm depth) of 49, 24, 116, and 1,151 mg kg^{-1}, respectively.

2.2 | Experiment 1

Treatments were the split-plot arrangement of three sunn hemp genotypes (Ubon, Blue Leaf, and Tropic Sun; main plots) and two residue management strategies (complete biomass removal or leaving the biomass on the soil surface; split-plots); distributed in a randomized complete block design with four replicates.

Plots were 6 × 6 m and sunn hemp was seeded using a drill (Pasture Pleaser) with 28 kg ha^{-1} seeding rate on 7 May 2018 and 3 May 2019. Plots were fertilized with 30 kg N ha^{-1}, 13.2 kg P ha^{-1}, and 25 kg K ha^{-1} 2 wk after germination, following recommendations from Mylavarapu et al. (2015). The experimental area was irrigated at the sowing or after 7 d without rainfall events. Each irrigation event provided the equivalent of 24-mm rainfall. In 2018 and 2019, the experimental area received the total irrigation amounts of 24 and 96 mm, respectively. Plots were harvested 8 wk after seeding and biomass was either completely removed or left on the soil surface.

During the experimental period, daily temperature and accumulated precipitation were recorded at the Florida Automated Weather Network (FAWN) measurement site at the research center and presented on Table 1.

2.3 | Biomass accumulation and nutritive value

A 2 × 2 m area was harvested at ground level in the center of each plot and used to estimate biomass accumulation. A subsample was dried at 55 °C for 72 h and grounded to pass a 1-mm screen in a Wiley mill (Udy Corporation). Samples were analyzed for in vitro digestible organic matter (IVDOM) using the two-stage technique described by Tilley and Terry (1963) and modified by Moore and Mott (1974). Total N concentration was analyzed by dry combustion, using a Flash EA 1112-NC elemental analyzer (CE Elantech). Nitrogen content was calculated as the product of tissue N concentration (g N kg DM^{-1}) multiplied by biomass (kg DM ha^{-1}) and expressed as kg N ha^{-1}. Lignin concentration (g kg organic matter $[OM]^{-1}$) was analyzed using sulfuric acid immersion of acid detergent fibers (ANKOM fiber analyzer), drying, and weighing the final product (ANKOM Technology, 2020).

2.4 | Potential pathogenic microbial populations

The *Fusarium*, *Pythium*, *Sclerotinia*, and *Sclerotium* fungi population were at the beginning (initial) and the end of each growing season (2018 and 2019) in the 2-yr experimental period. *Fusarium* and *Pythium* determination was performed by the count plates technique. For *Fusarium*, a semi-selective peptone-PCNB agar was used, detecting later macroconidia and chlamydospores at 100–200× magnification, detailing the presence, size, and shape of these distinctive structures (Leslie & Summerell, 2006). For *Pythium*, the colonies incubation were performed in a PARP agar, followed by a morphologic examination by stereoscopy at 10–20x magnifications, distinguishing fungus features as a fast growing rate, no cross walls in the young mycelium and wide, highly branched hyphae (Morita & Tojo, 2007). For *Sclerotinia* and *Sclerotium* microorganisms, counting was performed by the wet-sieving technique. The material released from the soil particles passed through a 0.6-mm diam. opening sieve, swirled to suspension, and recovering the buoyant particles later. Finally, counting was done by microscopy (Punja, 1985).

2.5 | Experiment 2

Experiment 2 was conducted in the same experimental area as Experiment 1. Treatments were the factorial arrangement of three sunn hemp genotypes (Ubon, Blue Leaf, and Tropic Sun; main plots) and two biomass management strategies (biomass incorporated into the top 15-cm soil depth or placed on the soil surface) distributed in a randomized complete block design with four replicates. The in-situ litter bag technique was used to estimate biomass and N disappearance (Dubeux et al., 2006). Bags were placed in the plots in July 2018–2019 and the last bags were retrieved in June 2019–2020, after a 320-d incubation period. In Florida, sunn hemp is seeded in the spring after the harvest of a winter horticultural crop and the harvest or soil incorporation usually occurs in the summer (July). Although the subsequent horticultural crop is usually seeded 6 mo after sunn hemp cultivation (180 d), the 320-d incubation period was selected to evaluate the potential decomposition of the material over an extended incubation period. Twelve grams of oven-dried sunn hemp sample were placed in 15 × 30-cm nylon (75-μm pores) bags. Each bag

TABLE 1 Mean air temperature and monthly rainfall at the experimental site in 2018–2019

Month	Temperature			Rainfall		
	2018	2019	20-yr mean	2018	2019	20-yr mean
	˚C			mm		
Jan.	14.0	15.6	15.4	68.8	94.7	48.8
Feb.	21.1	20.9	17.3	13.5	90.9	49.4
Mar.	17.0	19.6	18.9	11.9	45.2	53.1
Apr.	21.5	22.5	21.6	60.7	71.6	58.0
May	23.6	25.6	24.1	344.2	101.9	96.7
June	26.3	26.9	25.8	126.2	136.7	208.1
July	26.7	26.7	26.4	126.5	128.8	170.9
Aug.	26.6	27.0	26.6	168.4	156.2	227.6
Sept.	27.0	26.8	26.0	131.3	22.6	171.7
Oct.	24.9	25.7	23.5	39.9	85.9	52.8
Nov.	20.7	19.6	19.4	57.7	26.2	36.8
Dec.	17.9	18.7	17.4	163.1	66.3	54.0

maintained a similar leaf/stem ratio from the herbage mass sampling. Bags were placed on the soil surface or incorporated at 15-cm depth within each experimental unit and incubated for 0, 10, 20, 40, 80, 160, and 320 d. The incubation time intervals and length were similar to those proposed by Mulvaney et al. (2017).

After each incubation time, the bags retrieved were placed in a forced-air oven set at 55 ˚C for 72 h, cleaned with a hand brush, and weighed. Residual material in the bags was ground through a 1-mm screen and analyzed for OM, N, and lignin/N ratio. Organic matter was determined by ashing dry matter samples at 500 ˚C for 4 h (Moore & Mott, 1974). Nitrogen and C concentrations were analyzed via dry combustion (CE Elantech). Lignin concentration was obtained as described for Experiment 1. Lignin content was calculated by multiplying the lignin concentration by the OM biomass in the bag (g bag^{-1}). Lignin/N ratio was obtained by dividing lignin content (g bag^{-1} OM) by N content (g bag^{-1} OM).

Time-dependent responses were evaluated by fitting mathematical models. The inverse double exponential model was used to estimate the OM proportion that disappears after incubation. Nitrogen disappearance also followed this model, as described by Inubushi et al. (2003) (Equation 1):

$$Y = A\exp\left[1-\left(-k_1 x\right)\right] + (1{,}000 - A)\exp\left[1-\left(-k_2 x\right)\right] \quad (1)$$

where Y is the proportion of OM and N disappearance at time x; A is the initial proportion of material in the active pool, k_1 is the active pool decomposition rate, and k_2 is the slow pool decomposition rate constants (g kg^{-1} OM d^{-1}).

Half-life was calculated as: HL = 0.693 k^{-1}, where HL is time in days when the material reached half decomposition, and k correspond to the overall decomposition rate constant (Walela et al., 2014).

Lignin/N ratio followed a linear plateau model described by (McCartor & Rouquette, 1977) (Equation 2):

$$Y = A + B\,(x - C) \quad (2)$$

where Y is the lignin/N ratio at x time; A is the initial ratio; B is the rate of increase in ratio from beginning of incubation until the plateau stage is reached (g kg^{-1} OM d^{-1}), and C is the day in which the ratio reaches the plateau.

2.6 | Statistical analysis

Data were analyzed by fitting mixed-effects models using the RStudio software (R Core Team, 2020). In Experiment 1, fixed effects from biomass accumulation and nutritive value included genotype and year; while for the microbial population suppression fixed effects were genotype, biomass management, and year. Random effects were blocks and their interactions. Microbial populations for each experimental unit were log-transformed before statistical analyses ($\log_{10}$) to conform to homoscedasticity.

In Experiment 2, fixed effects were genotype, biomass incorporation, time of incubation, and year. Random effects were blocks and its interactions. Time of incubation was analyzed as a repeated measurement. Organic matter and N disappearance, and lignin/N were analyzed by fitting a nonlinear model by ANOVA. Treatments were considered different when $p \leq .05$. Interactions not discussed in the results were not significant ($p > .05$). To validate each best curve fit, Pearson

TABLE 2 Year effect on sunn hemp biomass accumulation, N concentration, N content, and lignin concentration. Values are means of $n = 24$

	Year			
Response	**2018**	**2019**	**SE**	***p* value**
Biomass accumulation, kg DM ha^{-1}	3,285	5,576	66.2	.0004
Tissue N concentration, g kg^{-1}	19	24	0.2	.0003
Tissue N content, kg N ha^{-1}	62	133	1.8	<.0001
Lignin, g kg^{-1}	134	93	1.1	.0001

correlation was performed in all models ($r \geq .5$), comparing the fit of the modeled curve with the real data.

3 | RESULTS AND DISCUSSION

3.1 | Experiment 1

3.1.1 | Biomass accumulation and nutritive value

There was a 70% greater biomass accumulation in 2019 than 2018 for all genotypes; however, there was no genotype or genotype × year interaction effects (Table 2). The experimental area has poorly drained soils and the excessive rainfall in May 2018 (Table 1) likely contributed to the reduced biomass accumulation that year. Excessive soil moisture reduces the O_2 proportion in the soil pores, thereby decreasing root aerobic respiration and ATP synthesis (Lambers et al., 2008). Additionally, excessive soil moisture can force ethylene accumulation, inhibiting root elongation and subsequently affecting the legume performance (Pessarakli, 2001). Treadwell and Alligood (2008) reported that sunn hemp germination may be negatively affected by heavy rains during the first weeks after planting. Comparing with other warm-season legumes, Cherr et al. (2006a) reported that sunn hemp may have lesser biomass accumulation than pigeon pea [*Cajanus cajan* (L.) Millsp.] and centro (*Centrosema pubescens* Benth.) in tropical regions; however, there was a variation in the biomass accumulation of all species due to different edaphoclimatic conditions.

There was a 20% greater N concentration in 2019 for all genotypes (Table 2), probably due to a partial residual effect of N decomposed from the sunn hemp cultivated in 2018. Additionally, the excessive soil moisture in May 2019 could have affected soil N-cycling microbial populations (Orozco, 1999). Soil N-fixing (*Rhizobium, Azospirillum*, etc.) and nitrifying microorganisms (*Nitrosomonas*, *Nitrosospira*, etc.) require aerobic conditions to perform their metabolic processes (Robertson & Groffman, 2015). Hence, excessive soil moisture could increase anaerobic conditions and N loss by lixiviation (Brady & Weil, 2017), affecting N-cycling microorganisms and decreasing the available N in the soil (Sylvester-Bradley et al., 1988; Wetselaar & Ganry, 1982). In addition, there was a genotype effect on N concentration. Tissue N concentration of Blue Leaf was 21% greater than Ubon, while Tropic Sun was intermediate and did not differ from either of the other genotypes (Table 3). Jaramillo et al. (2020) observed that Blue Leaf had greater N concentration than Tropic Sun (referred as Crescent Sun in the manuscript) due to high N fixation. Although Blue Leaf did not differ from Tropic Sun in this trial, the observed greater N concentration in Blue Leaf than Ubon may be due to greater N fixation, because N fertilization and soil characteristics were similar among genotypes.

There was a 114% greater N content on sunn hemp in 2019 compared with 2018 (Table 2) but there was no genotype × year interaction effects. The reduced biomass accumulation and N concentration resulted in lesser N content in 2018. However, the N content calculated for 2018 is still within the range reported by Jaramillo et al. (2020) and Garzon et al. (2021) for sunn hemp in northern and southern Florida; that is, 46–72 kg N ha^{-1}. Conversely, the 2019 N content was greater than 2018 due to the greater biomass accumulation (Table 2), and values were similar to those reported by Mosjidis et al. (2013) in northern Florida (145–180 kg N ha^{-1}).

There was a genotype effect on IVDOM, and this effect occurred because Ubon had the least IVDOM (577 g kg^{-1}) compared with other genotypes (mean = 604 g kg^{-1}; Table 3). The IVDOM is affected by the proportion of soluble and insoluble compounds in the plant material, such as cell wall and phenolic compounds (Mertens & Grant, 2020; Sollenberger & Cherney, 1995); however, lignin concentration did not differ among genotypes (mean = 114 g kg^{-1}). The IVDOM of sunn hemp may be affected by the presence of pyrrolizidine alkaloids, which are accumulated in the foliage, flowers and seeds, and have detrimental effects on the ruminal microbial population (Mosjidis et al., 2012). Although these alkaloids were not quantified in this study, Ubon has earlier flowering than the other genotypes (Garzon et al, 2021) and the flowers have greater concentration of the alkaloids (Mosjidis et al., 2012). Nonetheless, the N and IVDOM concentrations in the three sunn hemp genotypes are above the maintenance requirements for nonlactating and lactating beef cows and can be effectively used as forage (National Academies of Sciences, 2016).

Sunn hemp lignin concentration was 44% greater in 2018 compared with 2019 (Table 2) but there was no genotype or genotype × year interaction effects. Lignin is a complex phenolic polymer that provides strength, rigidity, and hydrophobicity to cell walls. Its accumulation in the tissues is

TABLE 3 Genotype effect on sunn hemp N concentration and in vitro digestible organic matter (IVDOM) concentration. Values are means of $n = 24$

	Genotype				
Response	**Ubon**	**Tropic Sun**	**Blue Leaf**	**SE**	***p* value**
Tissue N concentration, g kg^{-1}	19b	21ab	23a	0.2	.04
IVDOM, g kg^{-1}	577b	607a	601a	0.1	.02

Note. Means followed by different lowercase letters within rows are different ($p \leq .05$).

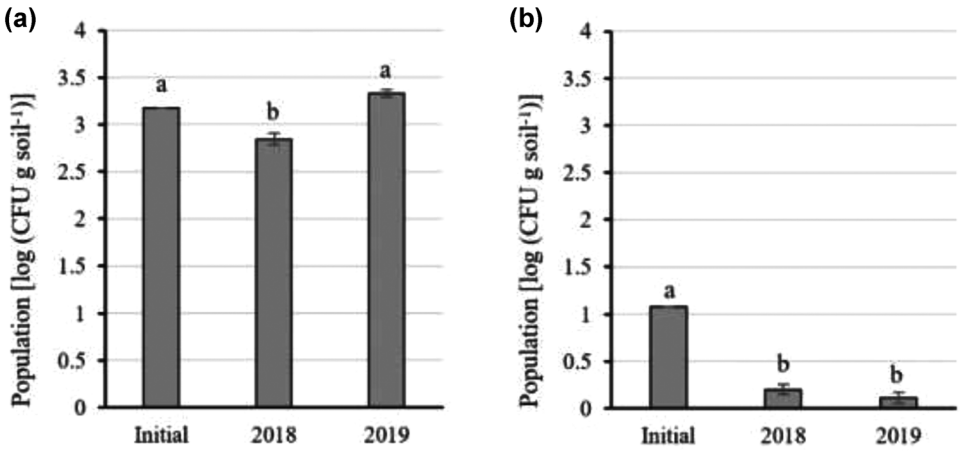

FIGURE 1 Year effect of sunn hemp on (a) *Fusarium* and (b) *Sclerotium* populations. Columns with different lowercase letters are different ($p \leq .05$)

affected by plant species, age, or as an adaptive process to confront abiotic stresses (Cabane et al., 2012). Flood conditions promote the synthesis of biochemicals to inhibit root elongation, and those compounds may also be involved in the lignin synthesis (Bhardwaj et al., 2014; Yamaguchi et al., 2010). Thus, soil water saturation could have increased sunn hemp lignin concentration in May 2018.

3.1.2 | Potential pathogenic soil microorganisms

There was a 72% decrease in the *Sclerotium* from the initial population to 2018 and there were no differences in 2018 and 2019 (Figure 1b). *Fusarium* population decreased 13% from the initial to 2018 but increased in 2019 (Figure 1a). There was a low residual effect of sunn hemp or a high adaptation potential for *Fusarium*, especially observing the higher quantity of organisms in the soil compared with *Sclerotium*.

There were sunn hemp genotype × year and biomass management × year interactions for *Pythium* population (Table 4). The *Pythium* population in plots cultivated with Blue Leaf did not change from the initial population to 2018 (mean = 2.25 log colony forming unit [CFU] g soil^{-1}) but decreased in 2019 (0.9 log CFU g soil^{-1}). Conversely, the Ubon and Tropic Sun genotypes decreased 32% the *Pythium* population in 2018 but there was no difference between 2018 and 2019. Although there was a decrease from the initial population to 2018 and 2019 in both biomass management treatments, the magnitude of the decrease was greater in plots with no removal in 2019.

TABLE 4 Year effect on *Pythium* population by sunn hemp genotype and biomass management after harvest

	Year			
Treatments	**Initial**	**2018**	**2019**	**SE**
	———log(CFU g soil^{-1})———			
Genotype				
Blue Leaf	2.6aA	1.9aA	0.9bB	0.1
Ubon	2.6aA	1.7bA	2.1bA	
Tropic Sun	2.6aA	1.8bA	2.0bA	
SE	0	0.1	0.2	
Biomass management				
Removal	2.6aA	1.9bA	1.9bA	0.1
No removal	2.6aA	1.8bA	1.4bB	
SE	0	0.1	0.2	

Note. CFU, colony-forming unit. Means followed by different lowercase letters within rows are different ($p \leq .05$). Means followed by different uppercase letters within columns are different ($p \leq .05$).

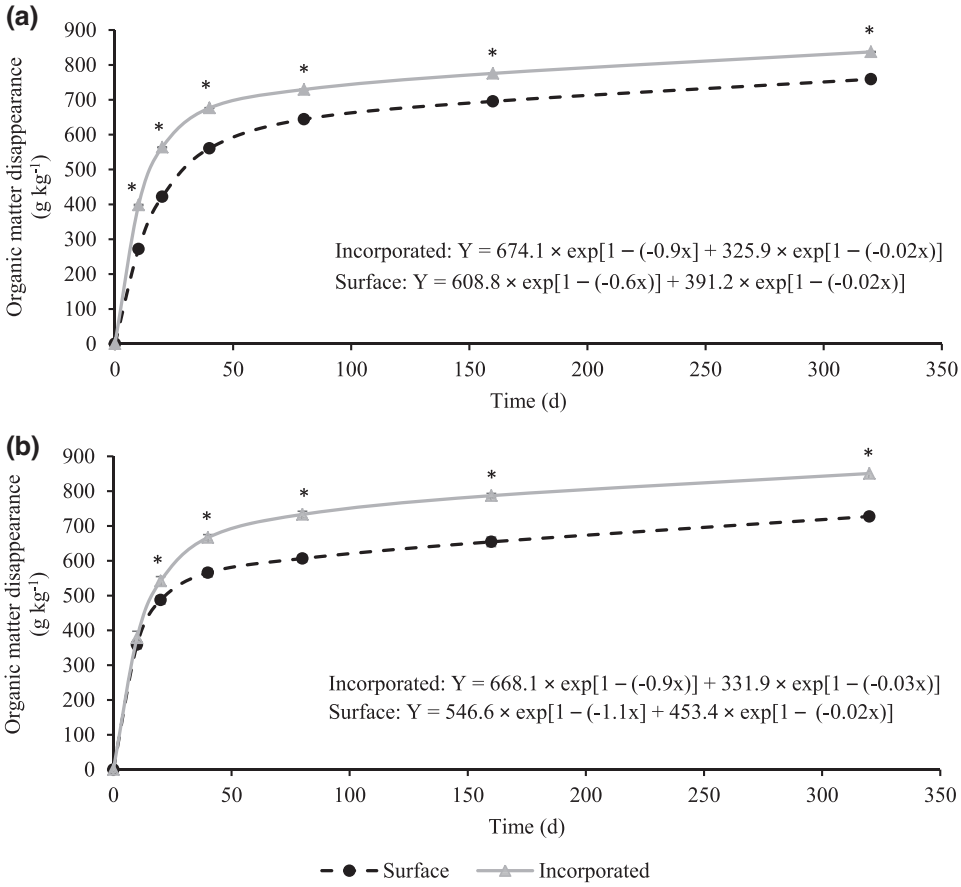

FIGURE 2 Sunn hemp organic matter disappearance on the surface or incorporated into the soil in (a) 2018 and (b) 2019. Means indicated with * were different (SE = 11.5, $p \leq .05$) within time

Sunn hemp produces pyrrolizidine alkaloids as secondary metabolites (Mosjidis et al., 2012) and stores them mainly in seeds and pods (Van Wyk & Verdoorn, 1990). Colegate et al. (2012) showed that the legume might also accumulate alkaloids in roots, stems, and leaves. However, there is no information in the literature about the differences in alkaloid concentration among the genotypes evaluated in this study, and the reason for the *Pythium* suppression differences among genotypes are unknown. Based on these results, it is plausible that maintaining sunn hemp biomass in the field favored alkaloid release to the soil, which then suppressed *Pythium* population.

No *Sclerotinia* populations were detected in the experimental area during the evaluation period.

3.2 | Experiment 2

3.2.1 | Organic matter disappearance

There was no genotype effect on OM disappearance; however, there was a biomass incorporation × incubation time × year interaction effect. The interaction occurred because the OM disappearance was approximately 14% less in the surface material than incorporated in both years, except at 10 d of incubation in 2019, with no difference among treatments (Figure 2). This could be reflected in a greater decomposition rate for the soluble material pool at the soil surface ($k_1 = -0.6$ vs. -1.1 for 2018 and 2019, respectively).

The half-life decomposition for the surface material required an additional 123 d to achieve a similar disappearance to the incorporated material in 2018 and 2019 (397 vs. 274 d, respectively, $p \leq .05$ SE = 33). These values are similar to the half-life decomposition of *Crotalaria spectabilis* Roth, *C. juncea* L., and *C. ochroleuca* G. Don, with 165, 266, and 315 d, respectively (de Sousa et al., 2019). Litter bags incorporated into the soil likely favor soil microbial access to sunn hemp residue, resulting in a faster decomposition (Alcantara et al., 2000). Similarly, Carvalho et al. (2008) measured the decomposition rate of several legumes used as cover crops in Brazil and observed that sunn hemp residues at 10-cm depth had 6% greater disappearance compared with residues left on the soil surface, with a greater effect before 90 d of incubation.

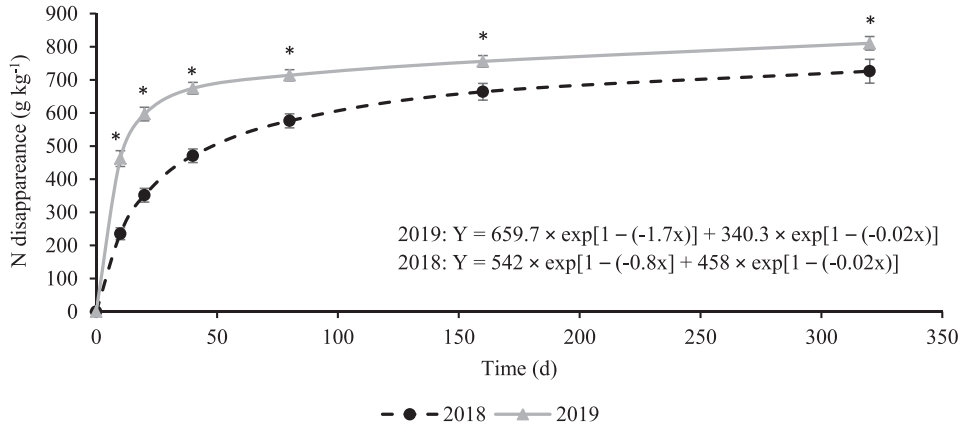

FIGURE 3 Nitrogen disappearance in sunn hemp organic matter decomposition (2018–2019). Means indicated with * were different (SE = 18.5, $p \leq .05$) within time

3.2.2 | Nitrogen disappearance

There was an incubation time × year interaction effect for N disappearance. The interaction occurred because there was no difference in between years in the 0 and 20 d after incubation; however, N disappearance was on average 19% greater in 2019 than 2018 from 40 to 320 d after incubation (Figure 3). The lack of difference in the first few days after incubation is likely due to time required to the microbes to colonize the plant material and start the decomposition process. After 40 d of incubation, greater N disappearance in 2019 likely occurred due to greater tissue N concentration and lesser lignin concentration (Table 2).

Nitrogen is a key element for soil microbial growth, especially in soils with low organic matter concentrations (Robertson & Groffman, 2015). The first phase of litter decomposition is defined by rapid litter organic matter disappearance and N release, which is rapidly consumed by soil microorganisms. This stimulates the microbial population growth and further increases the decomposition rate (k_1) (Berg & McClaugherty, 2008). However, part of the N is bound to litter low soluble compounds (such as lignin, among others), thus it cannot be released unless specific microorganisms break those chemical bounds (Crawford & Crawford, 1980). As a result, the second phase of decomposition have a slow N disappearance rate (k_2). Therefore, plant residues with greater lignin concentration likely have a decreased proportion of the N released during decomposition (Palm & Sanchez, 1991). Similarly to these results, Mulvaney et al. (2017) observed that approximately 750 g kg^{-1} of the N from groundnut mineralized after 335 d of incubation.

3.2.3 | Lignin/N ratio

There was a biomass incorporation × incubation time interaction effect to lignin/N ratio. In both years, the surface material had approximately 40% greater lignin/N ratio than the incorporated biomass at 40 d, and 66% greater lignin/N from 80 to 320 d of incubation (Figure 4). The incorporated samples likely had greater presence of soil microbes, which could have led to increasing N levels and decreased lignin/N ratio. (Yang & Zhu, 2015) examined the soluble organic compounds in microbial biomass and enzyme activities on the decomposition of tree leaf litter incorporated into the soil and suggested that litter decomposed faster and increased the microbial biomass under the soil surface after 42 d of incubation. Xu et al. (2016) reported that respiratory outputs per unit of microbial biomass were generally greater when the litter was incorporated into the soil, while analyzing the effect of N addition, temperature, and soil moisture on soil microbial respiration and biomass in the belowground decomposition of leaf litters.

The lignin/N ratio is a valuable indicator of net N mineralization rates, and it also indicates the synchrony between soil N supply and plant uptake (Dubeux et al., 2006). Kohmann et al. (2019) reported a range of 2–6:1 lignin/N ratio in the decomposition of rhizoma peanut (*Arachis glabrata* Benth.) during 126 d of incubation. Our study reported a 6–17:1 lignin/N ratio during the 320-d incubation period (Figure 4). The smaller lignin/N ratio range occurred because rhizoma peanut (*Arachis hypogaea* L.) had 31 and 63 g kg^{-1} of N and lignin concentration, respectively, at the initial decomposition material (Kohmann et al., 2018), compared with 22 and 114 g kg^{-1} of N and lignin in our study (Table 2).

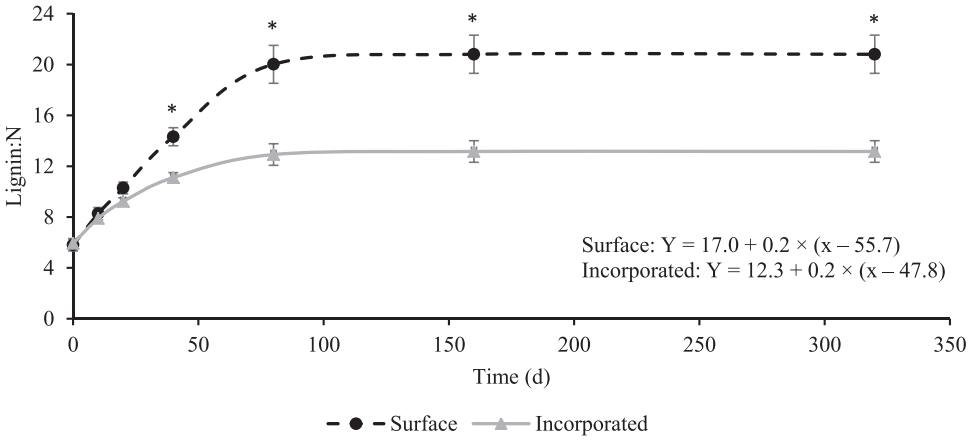

FIGURE 4 Lignin/N ratio of sunn hemp organic matter on the surface or incorporated into the soil. Means indicated with * were different (SE = 0.8, $p \leq .05$) within time

4 | CONCLUSIONS

The selection of the sunn hemp genotype is important due to differences in nutritive value, and suppression of potential pathogenic microbes in the soil. However, sunn hemp biomass accumulation may be greatly affected by weather conditions in South Florida. In addition, the cultivation of sunn hemp in the same area in consecutive years may have beneficial residual effects, which would result in greater biomass accumulation and N concentration in the 2nd year. It was observed that Blue Leaf had the greatest *Pythium* suppression over the 2-yr experimental period. However, sunn hemp was not effective to suppress *Fusarium* and *Sclerotium*. The incorporation of sunn hemp into the soil accelerated organic matter mineralization, which can be an important immediate source of N for the subsequent crop. Conversely, leaving sunn hemp residue on the soil surface was an effective management practice to decrease N mineralization rate and likely provide a steadier supply of N for the subsequent crop.

AUTHOR CONTRIBUTIONS

Jaime Garzon: Conceptualization; Data curation; Formal analysis; Project administration; Writing-original draft. Joao M B Vendramini: Conceptualization; Data curation; Funding acquisition; Methodology; Writing-review & editing. Maria Lucia Silveira: Data curation; Formal analysis; Investigation; Resources; Writing-review & editing. José C. B. Dubeux: Investigation; Methodology; Writing-review & editing. Lynn E. Sollenberger: Investigation; Methodology; Writing-review & editing. Hui-Ling Liao: Investigation; Methodology; Writing-review & editing. Philipe Moriel: Investigation; Methodology; Writing-review & editing. Hiran M. S. Silva: Investigation; Methodology; Project administration; Writing-review & editing. Vinicius Carreteiro Gomes: Investigation; Methodology; Project administration; Writing-review & editing. Igor M. Ferreira: Investigation; Project administration; Writing-review & editing. Nayara M. Alencar: Investigation; Methodology; Project administration; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Garzon, J., Vendramini, J. M. B., Silveira, M. L., Dubeux, J. C., Liao, H.-L., Sollenberger, L. E., Moriel, P., Silva, H. M. S., Gomes, V. C., Ferreira, I. M., & Alencar, N. M. (2023). Residue management and genotype effect on sunn hemp organic matter and nitrogen decomposition. *Agronomy Journal*, *115,* 261–272. https://doi.org/10.1002/agj2.21193