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Suitable Browse Species for Small Ruminants: Growth Patterns and Animal Preference

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ABSTRACT

Browse species supplement diet, increase forage choices, and expand grazing opportunities for small ruminants. However, information on the foliage-development patterns of browse species and the appropriate time to begin harvesting/browsing with small ruminants is lacking in the southeast USA. The objectives of this study were to 1) determine the growth patterns of browse species available in grazing lands and 2) evaluate small ruminants' preference for these species. Browse species in woodland (2.8 ha) and browse-research (5.2 ha) sites were identified and marked in early winter 2019. The date when the first leaf sprout occurred was recorded, and canopy-development data were taken fortnightly after the first sprout until the full canopy developed. Eight Kiko wethers and five Katahdin rams were co-stocked rotationally in three woodland plots (0.4 ha each) from mid-May to mid-October 2019. The extent of defoliation of browse species by animals was assessed using defoliation scale ranging from 0 to 5 (0 = no defoliation, 5 = 80-100% defoliation). Canopy-development data were analyzed using the GLM procedure and plant-preference data with the Mixed procedure in SAS 9.4. Nine species began sprouting in early February, seven by mid-March, and three by late April. Species varied in attaining the full canopy ranging from April 21 to May 21. Animals showed a high preference for seven species, moderate preference for nine, and least for 11. Results show that browse foliage can be ready for harvest beginning late April to mid-May. Moderate to highly preferred species can be used to develop browse programs or manage these species with small ruminants if present in woodlands.

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1. Introduction

Leaves, shoots, tender twigs, and young stems of woody plants consumed by livestock to meet their dietary requirements are considered browse (Latt et al., 1993; Paneru et al., 2019). Browse plays a crucial role in ruminants' diet in most parts of the world (Tolera et al., 1997). Papachristou et al. (2005) reported that a higher proportion of browse was included in small ruminants' diet (mixture of oak browse 45% and other woody browse species 22%) compared to herbaceous species (33%) of oak forest stands in Greece. At least 40% of the goat diet came from browse species in a mixed Mediterranean environment (Landau et al., 2000). Bartolomé et al. (1998) found that 71 species were common to both goat and sheep diets out of 111 species identified from mountain rangeland consisting of *Quercus ilex* woodland and *Calluna vulgaris-Erica arborea* heathland. Karki (2017) reported that browse (shrubs, trees, and vines) species available in the woodland understory of southeastern USA increased the variety in small ruminants' diet. The study further explained the importance of browse species in minimizing the infestation of gastrointestinal (GI) parasites in small ruminants for two reasons. First, the foliage of these species remains farther from the ground surface, and thus, the chance of small ruminants consuming the GI-parasite larvae would be significantly minimized. In areas where the climate stays warm and humid during spring, summer, and fall or most parts of these seasons, and gastrointestinal parasites challenge the health of small ruminants, the inclusion of quality browse species preferred by small ruminants would be promising to keep animals healthy and productive. Second, many browse species consist of condensed tannins (Khatri, 2016; Khatri et al., 2016a) that are detrimental to GI nematodes (Min et al., 2004).

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Woodlands of the southeast USA present numerous volunteer browse species that can be utilized by small ruminants (Khatri et al., 2016a; Karki, 2017; Bhattrai, 2019). However, information on sustainably managing browse species available in grazing lands is scant, especially an appropriate time to begin stocking animals in plots containing these species in the growing season. Stocking animals in the grazing plots containing browse species when they are not fully grown or in the dormant stage may harm browse plants. Poudel et al. (2017) reported severe damage caused by Kiko wethers and Katahdin rams when stocked in plots consisting of dormant browse species. Poudel et al. (2017) reported that the highest level of damage was found on mulberry (*Morus rubra* L.), followed by mimosa (*Albizia julibrissin* Durazz.). Moreover, they found that 53% of the dormant browse plants were damaged to some extent by small ruminants.

Harvesting browse foliage at a very early growth stage harms the survival, growth, foliage production, and persistency of browse species based on the same principle that is applicable to herbaceous forages (Karki, 2013a). Karki (2013b) emphasized that forages should be grazed when they attain their most vegetative growth and store enough food required for regrowth after they are defoliated (grazed). Browse defoliation before enough foliage growth reduces vegetation yield and persistence (Karki, 2013ab). Once browse foliage attains the full canopy, animal stocking should begin and managed with desired level of defoliation (50% or less) throughout the browse growth season. To avoid or minimize the damaging effect on browse species because of premature defoliation or rejection of these species by animals because of lignification, information on their growth patterns and the time to attain a full canopy is needed.

Understanding small ruminants' preference for browse and herbaceous plants is necessary for maximizing the utilization of these species in woodlands. Previous studies have reported goats' selecting more browse species than sheep, which mostly preferred herbaceous vegetation. Rogosic et al. (2006) found goats consuming nearly double the shrub material consumed by sheep in holly oak-maquis-type shrublands in Croatia. Similarly, Ferreira et al. (2013) described that goats' diet generally comprised woody browse, whereas sheep's diet mainly composed of herbaceous vegetation. The study further reported that sheep also selected woody browse when herbaceous species were limited in the grazing land. Bhattrai et al. (2020) reported that goats mostly browsed woody species and sheep consumed herbs when stocked in separate woodland plots in the southeastern USA.

Co-stocking goats and sheep may efficiently utilize diverse plant species present in certain grazing lands such as woodlands in the southeast USA. The complementary grazing preferences of goats and sheep in various grazing lands cited above indicate a potential for co-stocking of these animals for efficient utilization of diverse plant species present in woodlands in the southeast USA. However, such a prospect has not been evaluated, and the preference for understory browse in woodlands when goats and sheep are co-stocked is not reported from the southeast USA. The objectives of this study were to 1) determine the growth pattern of browse species available in grazing lands and 2) evaluate small ruminants' preference for these species.

2. Materials and Methods

2.1. Study Site and Animals

For Objective 1, an observational study was conducted at Atkins Agroforestry (6 plots- 2.8 ha) (32°26'35.7" N 85°43'56.5" W; Fig. 1 A) and Browse (11 plots- 5.2 ha) (32°26'00.7" N 85°43'00.2" W; Fig. 1 B) Research and Demonstration Sites of Tuskegee University, Tuskegee, Alabama, USA. Eighty percent of the total study area was occupied by Cowarts loamy sand (5- 15% slopes) and 20% was by Uchee-loamy sand (1-5% slopes) at the Atkins site. At the Browse site, 95% of the area had Cowarts loamy sand (5-15% slopes) and 5% had Marvyn loamy sand (2-5% slopes) (USDA-NRCS, 2018). Various types of shrubs, vines, and herbaceous species were present at both study sites. Each plant species included in the study was an experimental unit.

The study related to Objective 2 (vegetation preference) was conducted only at the Atkins Agroforestry Research and Demonstration site (3 plots – 0.4 ha each) because of differences in plant-community characteristics between these two sites. Eight mature Kiko wethers (57-month-old, live wt. 74±2.6 kg) and five Katahdin rams (38-month-old, live wt. 90±5.2 kg) were used in the study. Both animal species were co-stocked rotationally (8 rotational grazings) in three woodland plots (0.4 ha each) from mid-May to mid-October 2019, during which animals were not supplemented with any feedstuffs. The animal stocking in the research plots ended in mid-October as the understory foliage started depleting significantly by then. Both animal species had an earlier experience of grazing in the woodland plots when they were used for mono-species grazing studies. All plant species included in the study for Objective 1 were not present in plots used for the study related to Objective 2.

2.2. Plant Identification and Tagging for Determining the Growth Pattern

Browse species present in woodland plots (2.8 ha) and browse plots (5.2 ha) were identified (a total of 31 species, with at least 10 replications for each species), and each species was marked with colorful ribbons in the last week of January 2019 for growth-pattern study. Observations were made fortnightly on leaf sprouting and canopy development of the selected species beginning February 7 until May 21, 2019.

2.3. Leaf Sprouting and Canopy Development of Browse Species

For leaf sprouting, data collection began when browse species overcame the dormancy period and started sprouting (February 7). On the very first date when any browse species among the 31 identified species started sprouting, the sprouting (%) was recorded. Once sprouting began, observations were repeated on each species every 14 days for assessing the canopy development until these species reached the full canopy (May 21). A vertical, 1.26-m^2 (2.1 m x 0.6 m) photoplot consisting of 56 squares (0.15 m x 0.15 m) (USDA-FS, 1996) (Fig. 2) was used to assess the canopy-development percentage. Canopy coverage of browse species was quantified within the 56 squares of the vertical photoplot on a scale ranging from 0 to 100%. The extent of canopy development on each observation date for each browse species was scored based on the number of squares of the vertical photoplot covered by the foliage out of 56 squares. Full canopy development (100%) was determined when all squares within the growing height of each plant species were covered by its foliage. Early-, intermediate-, and late-growing species were categorized based on the date they started sprouting and reached the full canopy (Table 2).

2.4. Animal Preference for Understory Vegetation

Forty observation spots per plot (3 plots at Atkins site) were randomly selected to represent the entire plot area, and the extent of defoliation by

animals on plants that were present within a 1.2-m radius of each observation spot and available up to 2.1 m height from the ground surface were recorded (10 observations/spot) within two days after animals were moved out of the plot at each rotation (Fig. 3). Pre-structured data sheets, which contained observation date, observation spot, plot number, name of browse species, and preference scale, were used to record the extent of defoliation. The preference scale ranged from 0 to 5, in which 0 indicated no defoliation and 5 indicated more than 80% defoliation (Karki, 2017; Table 3). Animals' preference for longleaf pine (*Pinus palustris* Mill.), loblolly pine (*Pinus taeda* L.), common ragweed (*Amborisa artemisiifolia*), and hackberry (*Celtis occidentalis* L.) were not listed in Table 7 because the foliage of longleaf pine and loblolly pine was mostly beyond the reach of grazing animals, and observation number for ragweed and hackberry was not enough to make a decision. In contrast, the remaining species were consumed by animals to various extent.

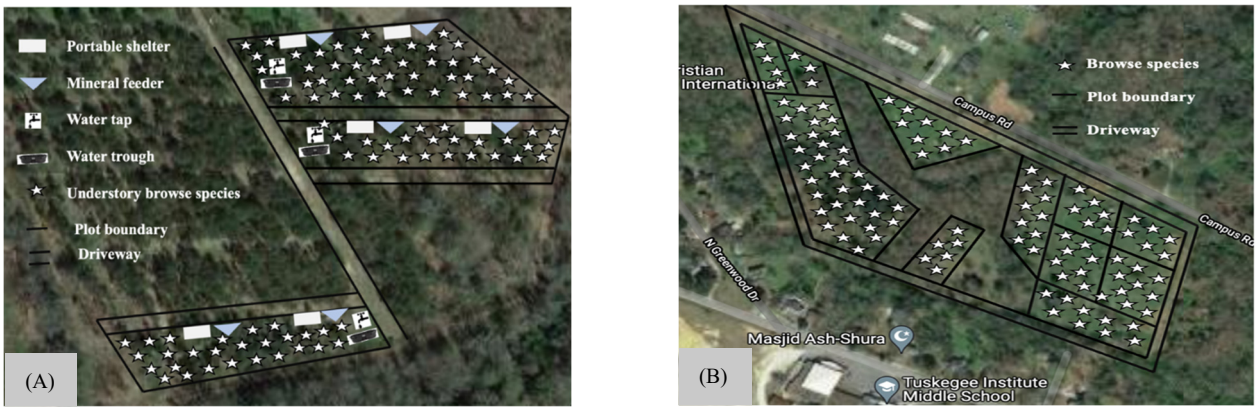

Figure 1. Study plots at Atkins Agroforestry Research and Demonstration Site (A) and Browse Research and Demonstration Site (B), Tuskegee University, Tuskegee, Alabama, USA (mid-May to mid-October 2019).

2.5. Data Analysis

2.5.1. Canopy Development and Vegetation Preference

Canopy-development data were analyzed using the GLM procedure in SAS v 9.4. The dependent variable was canopy coverage, and the independent variable was the browse species at each observation date. The significance level was set at 0.05. The GLM model used to analyze canopy development data is given below:

$Y_{ij} = \mu + \alpha_i(\beta_j) + e_{ij}$

Where, Y_{ij} = canopy development of i^{th} browse species (i=1-31) on j^{th} observation date (j=1-8), μ = grand mean, $\alpha i(\beta j)$ = interaction effect of i^{th} browse species at the j^{th} observation date, e_{ij} = error associated with the i^{th} browse species and j^{th} observation date.

Vegetation preference data were analyzed in SAS v 9.4 using the Mixed procedure with plot as a random factor, as shown in the model below.

$Y_{ij} = \mu + \alpha_i + e_{ij}$

Where, Y_{ij} = value of an observation (vegetation preference) taken on i^{th} plant species and j^{th} study plot, μ = grand mean, α_i = main effect of i^{th} plant species, e_{ij} = error associated with the i^{th} plant species and j^{th} plot (j=1-3).

Table 1. List of browse species identified from Atkins Agroforestry and Browse Research and Demonstration Sites, Tuskegee University, Tuskegee, Alabama, USA (February 7- May 21, 2019).

S.N.	Browse Species	Plant Category
1	American beautyberry (*Callicarpa americana* L.)	Shrub
2	Bartlett pear (Pyrus communis L.)	Tree
3	Blackberry (*Rubus* L.)	Shrub
4	Bush indigo (*Amorpha fruticosa* L.)	Shrub
5	Chinaberry (*Melia azedarach* L.)	Tree
6	Chinese privet (*Ligustrum sinensis* Lour.)	Shrub
7	Dogwood (Cornus florida L.)	Tree
8	Farkleberry (*Vaccinium arboreum* Marshall)	Shrub
9	Gallberry (*Ilex coriacea* (Pursh) Chapm.)	Shrub
10	Greenbrier (*Smilax* spp. L.)	Vine
11	Hackberry (Celtis occidentalis L.)	Tree
12	Hairy clustervine (Jacquemontia tamnifolia (L.) Griseb	Vine
13	Hickory (*Carya tomentosa* (Lam.) Nutt.)	Tree
14	Honeysuckle (*Lonicera japonica* Thunb.)	Vine
15	Kudzu (*Pueraria montana* (Lour.) Merr.)	Vine
16	Laurel cherry (*Prunus caroliniana* Aiton)	Tree
17	Mimosa (Albizia julibrissin Durazz.)	Tree
18	Muscadine (*Vitis rotundifolia*. Michx.)	Vine
19	Pecan (*Carya illinoinensis* (Wangenh.) K. Koch)	Tree
20	Peppervine (*Nekemias arborea* (L.) J. Wen and Boggan)	Vine
21	Persimmon (Diospyros virginiana L.)	Tree
22	Red cedar (Juniperus virginiana L.)	Tree
23	Rivercane (*Arundinaria* spp.)	Shrub
24	Southern red oak (*Quercus falcata* Michx.)	Tree
25	Sweetgum (*Liquidambar* L.)	Tree
26	Water oak (*Quercus nigra* L.)	Tree
27	Wild plum (*Prunus americana* Marshall)	Tree
28	Winged elm (*Ulmus alata* Michx)	Tree
29	Wisteria (*Wisteria* Nutt.)	Vine
30	Yaupon (*Ilex vomitoria* Aiton)	Shrub
31	Yellow jasmine (*Gelsemium sempervirens* (L.) W.T. Aiton)	Vine

Table 2. Classification of browse species based on their sprouting and canopy-development timeframe, Atkins Agroforestry and Browse Research and Demonstration Sites, Tuskegee University, Tuskegee, Alabama, USA (February to May 2019).

Browse class	Time of foliage development	
	Occurrence of first sprouts	Attainment of full canopy
Early grower	February 7	April 21
Intermediate grower	February 21-March 7	May 7
Late grower	March 21- April 7	May 21

Table 3. Preference scale used to categorize browse species based on their defoliation by Kiko wethers and Katahdin rams, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA (mid-May to mid-October 2019).

Preference scale	0	1	2	3	4	5
Vegetation consumed (%)	0	1-20	>20-40	>40-60	>60-80	>80-100

3. Results

3.1. Leaf Sprouting

Nine browse species showed the earliest sprout on February 7 (Table 4). Chinese privet (*Ligustrum sinensis* Lour.) had the highest leaf sprout (34%) followed by bartlett pear (*Pyrus communis* L.; 18%), wild plum (*Prunus americana* Marshall; 16%), blackberry (*Rubus* L.; 14%) and honeysuckle (*Lonicera japonica* Thunb.; 13%). The amount of leaf sprout in peppervine (*Nekemias arborea* (L.) J. Wen and Boggan), water oak (*Quercus nigra* L.), winged elm (*Ulmus alata* Michx), and yellow jasmine (*Gelsemium sempervirens* (L.) W.T. Aiton) ranged from (3-6%) on February 7. Six browse species began sprouting on February 21, when their leaf sprout ranged from three to six percent (Table 5). Five species began sprouting on March 7 (Table 5). Among the mid-season sprouting species, mimosa had the highest leaf sprout (16%), followed by hackberry (11%) and greenbrier (*Smilax* L.; 9%). Hickory (*Carya tomentosa* (Lam.) Nutt.) and farkleberry (*Vaccinium arboreum* Marshall) had the lowest leaf sprout (4-5%) among the five species that were found sprouting on March 7.

Eight browse species began sprouting much later in the season - on March 21, 42 days after the very first sprouting found on nine species (Table 6). Kudzu (*Pueraria montana* (Lour.) Merr.) had the highest leaf sprout (36%) among the eight species that were found sprouting late in the season followed by yaupon (*Ilex vomitoria* Aiton; 35%), rivercane (*Arundinaria* spp.; 29%), and hairy clustervine (*Jacquemontia tamnifolia* (L.) Griseb; 27%). American beautyberry (*Callicarpa americana* L.), bush indigo (*Amorpha fruticosa* L.), muscadine (*Vitis rotundifolia* Michx.), and Chinaberry tree (*Melia azedarach* L.) had less leaf sprouted (17-24%) than in other late-sprouting species. Only three browse species, gallberry (*Ilex coriacea* (Pursh) Chapm.), laurel cherry (*Prunus caroliniana* Aiton), and eastern red cedar (*Juniperus virginian*a L.), were the late-sprouting species that were found developing their first sprouts on April 7 (Table 6). Among these species, laurel cherry had the highest number of leaves sprouting (65%) followed by eastern red cedar (46%) and gallberry (25%).

Table 4. Browse species that developed sprouts and full canopy early in the growing season, Atkins Agroforestry and Browse Research and Demonstration Sites, Tuskegee University, Tuskegee, Alabama, USA (February to May 2019).

Plant species	First-sprout date	Leaf sprouting (%, LSMeans±SE)	Observation date					
			Feb. 21	Mar. 7	Mar. 21	Apr. 7	Apr. 21	May. 7
			Canopy coverage (%, LSMeans±SE)					
Bartlett pear (*Pyrus communis* L.)	Feb. 7	18 ± 1.7	28 ± 1.5	47 ± 1.5	72 ± 1.5	93 ± 1.5	100 ± 1.5	
Blackberry (*Rubus* L.)	Feb. 7	14 ± 1.2	32 ± 1.1	56 ± 1.1	75 ± 1.1	87 ± 1.1	100 ± 1.1	
Chinese privet (*Ligustrum sinensis* Lour.)	Feb. 7	34 ± 1.7	49 ± 1.5	58 ± 1.5	78 ± 1.5	89 ± 1.5	100 ± 1.5	
Honeysuckle (*Lonicera japonica* Thunb.)	Feb. 7	13 ± 1.2	17 ± 1.1	30 ± 1.1	78 ± 1.1	91 ± 1.1	100 ± 1.1	
Peppervine (*Nekemias arborea* (L.) J. Wen and Boggan)	Feb. 7	3 ± 1.7	3 ± 1.5	7 ± 1.5	24 ± 1.5	63 ± 1.5	90 ± 1.5	100 ± 1.5
Water oak (*Quercus nigra* L.)	Feb. 7	4 ± 1.2	8 ± 1.1	13 ± 1.1	31 ± 1.1	87 ± 1.1	100 ± 1.1	
Wild plum (*Prunus americana* Marshall)	Feb. 7	16 ± 1.4	22 ± 1.3	32 ± 1.3	61 ± 1.3	88 ± 1.3	100 ± 1.1	
Winged elm (*Ulmus alata* Michx)	Feb. 7	4 ± 1.2	8 ± 1.1	14 ± 1.1	54 ± 1.1	87 ± 1.1	100 ± 1.1	
Yellow jasmine (*Gelsemium sempervirens* (L.) W.T. Aiton)	Feb. 7	6 ± 1.7	6 ± 1.5	11 ± 1.5	22 ± 1.5	66 ± 1.5	91 ± 1.5	100 ± 1.5

Table 5. Browse species that delayed sprouting but achieved the full canopy early in the growing season, Atkins Agroforestry and Browse Research and Demonstration Sites, Tuskegee University, Tuskegee, Alabama, USA (February to May 2019).

Plant species	First sprout date	Leaf sprouting (%, LSMeans±SE)	Observation date					
			Feb. 21	Mar. 7	Mar. 21	Apr. 7	Apr. 21	May. 7
			Canopy coverage (%, LSMeans±SE)					
Dogwood (*Cornus florida* L.)	Feb. 21	4 ± 2.5	2 ± 2.2	4 ± 2.2	59 ± 2.2	93 ± 2.2	100 ± 2.2	-
Pecan (*Carya illinoinens*is (Wangenh.) K. Koch)	Feb. 21	6 ± 1.7	3 ± 1.5	9 ± 1.5	29 ± 1.5	78 ± 1.5	100 ± 1.5	-
Persimmon (*Diospyros virginiana* L.)	Feb. 21	5 ± 1.7	2 ± 1.6	6 ± 1.5	13 ± 1.5	80 ± 1.5	100 ± 1.5	-
Southern red oak (*Quercus falcata* Michx.)	Feb. 21	5 ± 1.7	3 ± 1.6	6 ± 1.1	9 ± 1.1	85 ± 1.1	100 ± 1.1	-
Sweetgum (*Liquidambar* L.)	Feb. 21	3 ± 1.2	1 ± 1.6	3 ± 1.5	29 ± 1.5	82 ± 1.5	94 ± 1.5	100 ± 1.5
Wisteria (*Wisteria* Nutt.)	Feb. 21	6 ± 1.7	4 ± 1.6	6 ± 1.5	26 ± 1.5	82 ± 1.5	100 ± 1.5	-
Greenbrier (*Smilax* L.)	Mar. 7	9 ± 1.2	-	5 ± 1.1	10 ± 1.1	57 ± 1.1	86 ± 1.1	100 ± 1.1
Hackberry (*Celtis occidentalis* L.)	Mar. 7	11 ± 2.5	-	7 ± 2.2	25 ± 2.2	57 ± 2.2	86 ± 2.2	100 ± 2.2
Hickory (*Carya tomentosa* (Lam.) Nutt.)	Mar. 7	4 ± 1.7	-	2 ± 1.1	15 ± 1.1	84 ± 1.1	100 ± 1.1	-
Mimosa (*Albizia julibrissin* Durazz.)	Mar. 7	16 ± 2.5	-	11 ± 1.5	25 ± 1.5	68 ± 1.5	100 ± 1.5	-
Farkleberry (*Vaccinium arboreum* Marshall)	Mar. 7	5 ± 1.7	-	2 ± 1.5	54 ± 1.5	92 ± 1.5	100 ±1.5	-

Table 6. Browse species that developed sprouts and full canopy late in the growing season, Atkins Agroforestry and Browse Research and Demonstration Sites, Tuskegee University, Tuskegee, Alabama, USA (March to May 2019).

Plant species	First sprout date	Leaf sprouting (%, LSMeans±SE)	Observation date				
			Mar. 21	Apr. 7	Apr. 21	May. 7	May. 21
			Canopy coverage (%, LSMeans±SE)				
American beautyberry (*Callicarpa americana* L.)	Mar. 21	17 ± 1.7	4 ± 1.5	49 ± 1.5	70 ± 1.5	100 ± 1.5	-
Bush indigo (*Amorpha fruticosa* L.)	Mar. 21	19 ± 1.7	7 ± 1.5	45 ± 1.5	58 ± 1.5	92 ± 1.5	100 ± 1.5
Chinaberry tree (*Melia azedarach* L.)	Mar. 21	24 ± 1.7	11 ± 1.5	52 ± 1.5	89 ± 1.5	100 ± 1.5	-
Muscadine (*Vitis rotundifolia* Michx.)	Mar. 21	21 ± 1.7	6 ± 1.5	63 ± 1.5	88 ± 1.5	100 ± 1.5	-
Kudzu (*Pueraria montana* (Lour.) Merr.)	Mar. 21	36 ± 1.7	18 ± 1.5	82 ± 1.5	100 ± 1.5	-	-
Rivercane (*Arundinaria* spp.)	Mar. 21	29 ± 1.7	9 ± 1.5	76 ± 1.5	94 ± 1.5	100 ± 1.5	-
Hairy clustervine (*Jacquemontia tamnifolia* (L.) Griseb)	Mar. 21	27 ± 1.7	11 ± 1.5	26 ± 1.5	75 ± 1.5	100 ± 1.5	-
Yaupon (*Ilex vomitoria* Aiton)	Mar. 21	35 ± 1.7	19 ± 1.5	44 ± 1.5	65 ± 1.5	88 ± 1.5	100 ± 1.5
Gallberry (*Ilex coriacea* (Pursh) Chapm.)	Apr. 7	25 ± 1.7	-	19 ± 1.5	34 ± 1.5	61 ± 1.5	100 ± 1.5
Laurel cherry (*Prunus caroliniana* Aiton)	Apr. 7	65 ± 2.5	-	50 ± 2.2	82 ± 2.2	92 ± 2.2	100 ± 2.2
Eastern red cedar (*Juniperus virginian*a L.)	Apr. 7	46 ± 2.5	-	40 ± 2.2	66 ± 2.2	85 ± 2.2	100 ± 2.2

Figure 2. A photoplot showing the full canopy development in a browse species, Browse Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA (February to May 2019).

3.2. Canopy Development

Sixteen browse species developed the full canopy by April 21 (Tables 4-6). Examining the successive canopy development pattern prior to reaching the full canopy, species showed different extent of canopy cover at different observation dates. By February 21, Chinese privet had the highest canopy cover (49%) followed by blackberry (32%), bartlett pear (28%), wild plum (22%), and honeysuckle (17%) (Table 4). By March 21, kudzu attained 18% canopy. The canopy cover attained by the remaining seven species by February 21 ranged from two to eight percent (Tables 4-5) while other three species showed canopy covers ranging from 2-11% by March 7 (Table5). Bartlett pear, honeysuckle, dogwood (*Cornus florida* L.), and farkleberry developed more canopy cover (91-93%) than Chinese privet (89%) by April 7, 14 days before all these species developed full canopies.

Hickory, southern red oak (*Quercus falcata* Michx.), water oak, wild plum, and winged elm developed similar amount of canopy cover (84-88%) as Chinese privet (89%) by April 7 although the canopy cover of these species was far below (2-22%) to that of Chinese privet (49%) by February 21. Kudzu was the species that began sprouting very late in the season by March 21 (Table 6), and hickory, mimosa, and farkleberry began sprouting on March 7 (Table 5) among the 16 species that developed full canopies by April 21. Mimosa, wisteria (*Wisteria* Nutt.), persimmon (*Diospyros virginiana* L.), pecan (*Carya illinoinensis* (Wangenh.) K. Koch), and kudzu (Tables 5-6) developed less canopy cover (68-82%) than Chinese privet (89%) by April 7; however, all these species developed full canopies (100%) by April 21.

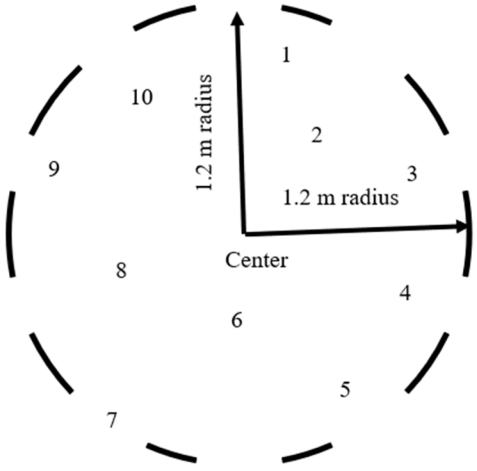

Figure 3. Schematic diagram showing observation points used to assess vegetation defoliation around each observation spot (center) in each study plot, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA (mid-May to mid-October 2019).

Ten browse species were found intermediate in developing their full canopies, which completed developing their full canopies by May 7 (Tables 4-6). Despite their attaining full canopies by the same date, the rate of

canopy growth varied among species. For example, peppervine, yellow jasmine, sweetgum, and rivercane developed 90-94% canopy cover by April 21 while American beautyberry, hairy clustervine, greenbrier, hackberry, muscadine, and Chinaberry tree developed 70-89% canopy cover by April 21. Among all the species studied, gallberry, laurel cherry, and eastern red cedar were the species that started developing canopy very late in the season (Table 6). Laurel cheery developed only 50% canopy followed by eastern red cedar (40%) and gallberry (19%) by April 7. Canopy development pattern among these species was similar with laurel cherry developing 92% canopy followed by eastern red cedar (85%) and gallberry (61%) by May 7, 14 days before all these species developed the full canopy. Gallberry developed about 40% canopy by May 21. Bush indigo and yaupon started developing canopy on March 21 and the canopy coverage was 19% for yaupon and 7% for bush indigo (Table 6) on that date and developed full canopies by May 21.

Table 7. Preference of Kiko wethers and Katahdin rams for woodland plant species, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA (mid-May to mid-October 2019).

Plant species	Preference scale (LSMeans ± SE)
Blackberry (*Rubus* L.)	5.0 ± 1.24
Sericea lespedeza (*Lespedeza cuneata* (Dum.Cours.) G. Don)	4.7 ± 0.23
Smooth sumac (*Rhus glabra* L.)	4.6 ± 0.47
Panicgrass (*Panicum* L.)	4.3 ± 0.44
Greenbrier (*Smilax* L.)	4.2 ± 0.12
Honeysuckle (*Lonicera japonica* Thunb.)	4.2 ± 0.19
Dogfennel (*Eupatorium capillifolium* (Lam.) Small)	4.2 ± 0.12
Winged elm (*Ulmus alata* Michx.)	4.0 ± 0.19
Muscadine (*Vitis rotundifolia* Michx.)	3.9 ± 0.12
American beautyberry (*Callicarpa americana* L.)	3.9 ± 0.10
American pokeweed (*Phytolacca americana* L.)	3.7 ± 0.32
Tropic croton (*Croton glandulosus* L.)	3.6 ± 0.62
Wild plum (*Prunus americana* Marshall.)	3.5 ± 0.31
Deerberry (*Vaccinium stamineum* L.)	3.3 ± 0.28
Yellow jasmine (*Gelsemium sempervirens* (L.) W.T. Aiton)	3.2 ± 0.47
Persimmon (*Diospyros virginiana* L.)	3.0 ± 0.16
Willow oak (*Quercus phellos* L.)	2.6 ± 0.27
Gallberry (*Ilex coriacea* L.)	2.5 ± 0.23
Yaupon (*Ilex vomitoria* Aiton)	2.2 ± 0.11
Hickory (*Carya* Nutt.)	2.1 ± 0.16
Water oak (*Quercus nigra* L.)	1.8 ± 0.14
Camphorweed (*Heterotheca subaxillaris* (Lam.) Britton & Rubsby)	1.6 ± 0.88
Southern red oak (*Quercus falcata* Michx.)	1.6 ± 0.18
Broomsedge (*Andropogon* L.)	1.3 ± 0.17
Sweetgum (*Liquidambar* L.)	1.2 ± 0.14
Farkleberry (*Vaccinium arboreum* Marshall)	1.2 ± 0.19
Goldenrod (*Oligoneuron* Small)	1.1 ± 0.44

3.3. Animal Preference for Woodland-Understory Plants

Seven species were highly preferred by animals (preference scale >4; Table 7). Blackberry was the most preferred species by wethers and rams throughout the study period (preference scale 5.0) followed by Sericea lespedeza (*Lespedeza cuneata* (Dum.Cours.) G. Don; 4.7), smooth sumac (*Rhus glabra* L.; 4.6), panicgrass (*Panicum* L.; 4.3), greenbrier (4.2), honeysuckle (4.2), and dogfennel (*Eupatorium capillifolium* (Lam.) Small; 4.2). Nine species were moderately preferred (preference scale 3-4; Table 7). Among moderately-preferred species, winged elm (4.0). muscadine (3.9) and American beautyberry (3.9) were preferred better compared to persimmon (3.0). Eleven species were least preferred (preference scale <3; Table 7), among which goldenrod (*Oligoneuron* Small) received the least score (1.1).

4. Discussion

4.1. Leaf Sprouting and Canopy Development

Browse species varied widely in developing their first leaf sprout. The early sprouters developed their earliest sprout in early February, and the late sprouters sprouted in early April, spanning over two months. Unlike the first-leaf sprout, the span for completing the full canopy across early to late growers was shorter, only showing a span of one month. Early growers attained the full canopy by April 21 and late growers by May 21. More than 50% (16) browse species developed full canopy by April 21, and five species, bush indigo, gallberry, laurel cherry, red cedar, and yaupon, took an additional month to reach the full canopy. Although red cedar and yaupon are evergreen species, we observed significant number of leaves yellowing and shedding in these species during fall in our previous study (Paneru et al., 2019). While maintaining a lush green growth throughout the year, these species lose old, mature leaves in the fall and develop new leaves in the spring, as found in the current study. The time needed for yaupon to develop its full canopy as observed in the current study was similar to the findings of Blair and Halls (1968) from upland pine-hardwood forest in the southern USA. From the same study, Blair and Halls (1968) reported two growth flushes in yaupon, in which the first was completed on May 21, and the second began in early August and continued until late October. The current study did not include the fall-growth period of browse species to compare with the second-growth results reported by Blair and Halls (1968).

The time needed for greenbrier (*Smilax* spp. L.) to develop a full canopy observed in the current study was similar to the findings of a study conducted in an east Texas pine forest (Halls and Alcaniz, 1972). Halls and Alcaniz (1972) reported that 95% of greenbrier canopy growth in wooded environments was completed by May 5, which was similar to the growth of this species found in the current study. They further reported that some of the greenbrier in open space would continue to grow new twigs until October, and greenbrier was one of the rapidly growing species in early spring in east Texas. Muscadine started sprouting on March 21 and developed a full canopy by May 7. From the same study, Halls and Alcaniz (1972) reported that the muscadine grape tended to grow less rapidly in the spring but continued to grow in the later season. Muscadine in the current study started sprouting late and developed a full canopy by early May. Dogwood, yaupon, and yellow jasmine (*Gelsemium sempervirens* (L.) W.T. Aiton) started sprouting on February 21, March 21, and February 7 and developed full canopy by April 21, May 21, and May 7, respectively in the current study. Halls and Alcaniz (1972) also reported that dogwood, yaupon, and yellow jasmine continued to grow during late summer and early fall, which extended the grazing period for deer.

With a difference of a month in full-canopy development between early and late growing browse species as found in the current study, animal stocking in grazing lands containing browse species should be planned accordingly by letting animals utilize the fully-grown foliage when they are available. In natural forests or woodlands, where understory plants are volunteer and maybe a mixture of early-, intermediate-, and late-growing species, it would be appropriate to start stocking animals around mid- to late May, when most understory plants would complete their full canopy. However, for developing browse plots, early-, intermediate-, and late-growing species can be planted in separate plots and let animals utilize 50%

of the foliage when ready, starting with early growers and then moving into intermediate- and late-grower plots, successively and rotate back in the same order when defoliated vegetation grows back to the full canopy.

The growth pattern of browse species found in the current study is valuable in promoting the health and overall sustainability of small-ruminant production systems, especially in the southeast US. Mid-April to mid-May in this region can be critical for forage supply as cool-season forages start to undergo dormancy and warm-season forages are still in early growth stage during this time. As browse species would be ready for animals' harvest beginning from around mid-April (early growers) to the third week of May (late growers), provision of browse plots or woodland grazing plots would fill the forage gap between cool- and warm-season growth periods. Moreover, as temperatures begin to rise from mid-April or early May, the problem of gastrointestinal parasites escalates in small ruminants. Use of grazing land with browse species can be helpful to break the parasite life cycle and safeguard animal health (Karki, 2017). This is because animals consume browse foliage usually situated at a safe height from the ground level and avoid picking up gastrointestinal-parasite larvae, which usually remain in herbaceous forages within a four-inch height from the ground.

The findings of the current study, combined with the results reported from an earlier study on leaf shedding of browse species (Paneru et al., 2019), provide valuable information on the availability of browse foliage during the productive grazing season. Out of 31 browse species included in an earlier study on leaf shedding patterns, four species lost 67-83% of leaves by the end of October, 11 species had 50% or more leaves intact by the end of November, and four species had 46-59% intact leaves until the end of December (Paneru et al., 2019). The current study shows that browse foliage would be available for animals to consume beginning sometime in mid-spring, and the leaf-shedding study revealed that browse foliage might be available until mid- to late-fall depending on the browse species.

4.2. Vegetation Preference

Of 31 browse species recorded from the study plots when wethers and rams were co-stocked, seven species were highly preferred (defoliation >60%) while nine species were moderately preferred (defoliation >40-60%). Mono-species-grazing studies conducted with either goats or sheep reported that goats had higher preference for sparkleberry *(Vaccinium arboreum* Marshall) than sheep, while sheep had higher preference for blackberry (*Rubus* spp. L.), dogfennel (*Eupatorium capillifolium* (Lam.), and Florida pusley (*Richardia scabra* L.) compared to goats (Bhattrai et al., 2022). Wethers showed dominant browsing behavior consuming vegetation present at higher strata, while rams predominantly grazed on the ground vegetation (Bhattrai et al., 2020). The current study established that co-stocking of goats and sheep is a more effective option to utilize the diverse understory vegetation in woodlands. With the target defoliation of browse foliage being 40-50% while leaving 50-60% foliage intact with plants to facilitate necessary photosynthesis for vigorous canopy re-growth for repeated, rotational stocking of grazing animals in a growing season (Karki, 2013), browse species with preference scale 3-5 (defoliation >40%) would be desirable candidates to be considered in the browse development program. Similarly, if browse species with a preference scale of 3 or above are present in the woodland understory, they could be well utilized or controlled using small ruminants. However, if the woodland understory consists of plants of low or zero preference for animals and needed to be controlled, alternative control methods, such as chemical, mechanical, or controlled burning, may be used.

The preference of small ruminants for different plant species observed in the current study has also revealed valuable insight into some plant species that could be grown in an agroforestry setting without hampering much of the tree components, such as oaks, sweetgum, and hickory. For these plant species, animals' browsing preference remained low throughout the grazing season, with defoliation below 40%. However, animals' preference for browse species may vary depending on the plant community present in the grazing land. If the browse species plants are sparsely scattered and the majority of species are herbaceous, browse defoliation would asymmetrically increase as we have observed such behavior of small ruminants in our other studies (unpublished). On the other hand, if there are abundant multiple browse species in grazing lands, animals would consume the most preferred ones and leave behind those less preferred (Bhattrai et al., 2021).

In a study on rangelands, Papachristou et al. (2005) reported that although almost all species available in the grazing land were browsed by small ruminants, only a small number of species accounted for a larger portion of their diets. Small ruminants in rangelands selected as many as 100 plant species in their diet, but most of the browse-associated diet contained less than 10% of the available plant species (Papachristou et al., 2005). In contrast, Khatri et al. (2016) observed that rotationally stocked young goats (6-8-month-old; stocking density 29 goats/0.4 ha) in woodlands showed a high preference (≥61% defoliation) for 26 out of 37 available plant species, both browse and herbaceous. In the current study with mature Kiko wethers and Katahdin rams co-stocked in woodlands, 17 of the 31 species were browsed well (defoliation >40%). The findings of the current study demonstrated that goats and sheep can be co-stocked and rotationally managed in woodlands to harvest the understory browse foliage during the period of browse growth without the need for feed supplement. Moreover, this study characterized the browse growth period, the earliest time in a growing season when the browse foliage would be ready for the first harvest or animal consumption.

5. Conclusions

Growth patterns (leaf sprouting and canopy development) varied widely among browse species (31) included in this study. The time taken by browse species from the first sprout to attaining the full canopy ranged from 4 to 14 weeks. Seven species, Bartlett pear, blackberry, Chinese privet, honeysuckle, wild plum, water oak, and mimosa, were early-season browse that developed sprouts and gained full canopy earlier in the growing season. Four species, gallberry, laurel cherry, eastern red cedar, and yaupon, took 14 weeks to develop a full canopy. Based on the growth pattern of browse species available in grazing lands, time for the initiation of grazing might vary, starting in mid-to-late April for early growers, early May for intermediate growers, and mid-to late-May for late growers. To develop browse plots for small ruminants, their preference for specific species should be considered and select the species with a preference scale of more than 3 (defoliation >40-100%). The use of small ruminants for controlling understory vegetation in tree production systems will be effective if most understory plants are preferred well and desirable tree species are less preferred than the understory vegetation by animals, especially when tree

branches and crowns are within the reach of grazing animals or trees are still vulnerable to the potential animal damage.

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