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Early Forage Biomass and Sward Structures of Native Warm-Season Grasses Established at Different Seedling Densities

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Abstract

Effects of transplanted seedling density and species on sward structure of native warm-season grass (NWSG) stands were compared in a randomized complete block design. About 6-week-old NWSG (big bluestem (BB, *Andropogon gerardii* Vitman), eastern gamagrass (GG, *Tripsacum dactyloides* L.), indiangrass [*IG*, *Sorghastrum nutans* (L.) *Nash*] and switchgrass (SG, *Panicum virgatum*) seedlings were transplanted in 45-cm wide rows on clean-tilled seedbeds. Within-row spacing was 30, 25, or, 20 cm giving 10, 12, and 15 plants m^{-2} as low, medium, and high seedling density, respectively. During establishment, the stands were allowed uninterrupted first year growth without fertilizers or irrigation but when necessary, tall-growing broadleaf weeds were mechanically removed. In the following spring, all dead standing biomass was mowed down to allow emerging tillers access to sunlight. During the second year after planting, early-spring basal diameters, row-length intercepted by the NWSG crowns, mid-summer sward heights, and percentage bare ground were determined. From the second June after planting, and for two consecutive years, plots were harvested twice $year^{-1}$ to assess forage biomass. Data showed that, unlike species, seedling density had no effect on the assessed parameters. Cumulative forage biomass, in kg DM ha^{-1}, was the least for GG (4901) at low and the most (18,245) for SG at high seedling density during the second year. Corresponding values for the third year were 4500 and 7799 kg DM ha^{-1}. Basal diameters ranged from 18 cm (BB) to 24 cm (IG) while percent row intercepts were from 6 (GG) to 46 (IG) with sward heights measuring 41 cm (IG) to 54 cm (GG). In each stand, percent ground cover by the NWSGs, and at every seedling density, averaged 60.5. Transplanting at

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≥10 plant m^{-2} resulted in harvest-ready stands by the second year of establishment. And while close spacing favored the NWSGs against weeds, data showed that an initial plant density of >10 plants m^{-2} may not result in increased forage production worthy the additional establishment cost. Data on response to fertility management and forage quality attributes are necessary for more reliable practical recommendations.

Keywords

Forage, Native Warm-Season Grass, Establishment, Transplant, Seedling Density, Yield, Cover, Habitat Quality, Sward Structure

1. Introduction

In the Southeast United States, frequent mid-summer forage shortages (summer slump), have made livestock producers more interested in the potential ability of native warm-season grasses (NWSGs) to increase forage productivity of their pasture systems. There is also a growing interest among land owners and/or managers, in other NWSG for bioenergy production, soil conservation, and other ecosystem benefits. Despite the unique abilities of NWSGs to remain productive during extended hot dry summers, most livestock producers are yet to confidently incorporate them into their forage systems due to uncertainties associated with their establishment. This is so because NWSG establishment is difficult, costly in both time and resources, and initial stands often exhibit poor performance. In most cases, such bad experiences are attributable to producers' reliance on conventional pasture establishment techniques and equipment that are not suitable for NWSGs. Usually, NWSG establishment is impacted by a combination of genetic and environmental factors as well as challenges associated with small seed size and weight [1]. Factors like low germination percentage and/or emergence, seed dormancy, low seedling vigor and survival, and severe weed competition, negatively impact the success of NWSG establishment. These factors necessitate research to seek faster establishment methods for NWSGs and avail information for their early integration into summer forage systems.

One alternative to seeded establishment of these NWSGs is raising seedlings in a weed-free environment and transplanting them onto clean seedbeds when growing conditions are optimum [2]. This is so because transplanting bypasses the most vulnerable seedling phases (germination, emergence and establishment) which gives the native grasses an edge over the annual weeds in competition for light, space, and soil-based resources. Effectively, transplanting may allow for rapid establishment of such species that might otherwise take longer to develop from seeds as previously reported [3] [4]. However, depending on the competitive ability of the major weeds in the area, transplanted seedlings may still suffer limited access to sunlight and resource competition. Additionally, the survival of transplanted native bunchgrasses still depends on the growing conditions during the transplanting season and the severity of challenges such as weed competition [4]. For a successful and faster establishment, therefore, specific weed control measures such as selective herbicide application, cultural practices, and staggered planting dates may still be necessary. When strategically employed, these different weed control practices can, effectively, minimize or avoid losses in crop biomass due to weeds competition. However, transplanting NWSGs too late in the season may negatively impact energy accumulation by shortening their active growing period and thus weaken the subsequent spring growth.

Another strategy is to manipulate the initial crop-weed ratio by varying the seedling density (transplant numbers). In wheat, increasing the crop density and spatial uniformity resulted in negative and positive effects on weed and crop yield, respectively [5] [6]. In maize, several studies have reported comparable yield responses among different planting densities [7] [8] [9]. However, the applicability of these approaches for mixed NWSGs stand establishment is not well understood. Differences in how NWSGs respond to defoliation may affect the reliability of transplanting as a weed control strategy. This is especially so if regrowth performance of one species is weak, a situation that may favor weed growth. In this study, therefore, the growth responses of BB, GG, IG, and SG stands at three different seedling densities to frequent defoliation were compared with respect to forage yield, sward structure, and species composition.

2. Materials and Methods

2.1. Location and Field Preparations

The study was conducted at Virginia State University's research farm (Randolph Farm) that is 37˚13''43'N; 77˚26''22'W, and 45 m above sea level and located in Chesterfield county, Virginia. Predominantly, soils at the farm are the Bourne series fine sandy loam (mixed, semiactive, thermic TypicFragiudults). By the summer of 2013, the area had experienced a 20 year June, July, and August average precipitation of 92, 113, and 121 mm with day temperatures of 30.2˚C, 32.1˚C, and 31.2˚C, respectively [10]. Prior to starting the experiment, the field had been fallowed for a year following several years of rotational corn-soybean row-cropping. However, during the fallow year, the field was plowed and harrowed, but not planted. During the fallow year, the field was mowed to weaken the thicket of annual weeds. Glyphosate {N-(phosphonomethyl) glycine} was applied to kill unwanted vegetation and the field cultivated with a row tiller prior to transplanting.

2.2. Seedlings Preparation, Plot Layout, and Planting

Starting late May of 2013, 5-cm deep degradable paper strip cups measuring 25 cm^2-top and 4 cm^2-bottom were arranged on perforated flats placed on a polyethylene-lined 120 × 240-cm table tops ready for raising seedlings in an open-sided high tunnel. Separate flats for BB, GG, IG, and SG, were seeded and watered sufficiently by bottom-up soaking until seedlings were ready for transplanting (about 6 week old). In early July, each species was planted in 3 × 1.5 m plots randomly assigned to four planting treatments [seed drilling/seeded, transplanting at low (L), medium (M), or high (H) seedling density] equivalent to 10, 12, and 15 plants m^{-2}, respectively, in a randomized complete block design (RCBD) with four replications. Rows were spaced 45-cm apart regardless of planting method. With transplanting, low, medium or high seedling densities were achieved at 30-, 25-, and 20-cm within-row plant spacing, respectively. Seedlings were firmed in to the soil by covering with ≥2-cm thick soil layer. Missing or improperly placed seedlings and/exposed roots were corrected, manually. To ensure smooth machine operations and seedling survival, transplanting was done about three days following a rainfall event. Planting was completed within two weeks with control plots seeded at ≤2-cm depth. High seed-rate recommendations by the Ernst Conservation Seeds, Inc., for forage stand establishment were followed.

2.3. Field Management

The transplanted stands were allowed uninterrupted first-year growth and, as necessary, tall-growing broadleaf weeds were chopped down using a hoe to minimize their competitiveness against the NWSGs seedlings. However, throughout the study, plots were not irrigated or fertilized. Early in the following spring, dead standing biomass was mowed down to allow emerging tillers access to sunlight.

2.4. Vegetation Measurements

To assess how seedling density and/or species might affect establishment success and sward structure, six early-spring basal diameter readings of the respective native grass stubbles were determined at about 2.5 cm above soil surface. This was carried out along two inside rows as indicators of the plant's cross-sectional area near the ground and four readings were recorded within each of three 1-m line segments at least 60 cm apart but excluding the outermost stubbles. During the same year and just before the first harvest, mid-summer sward height (cm) readings were recorded at 60-cm intervals. The sward height reading was recorded as the topmost level at which a meter stick held horizontally above the sward and against a Robel pole touched at least two leaves on separate rows. For the data analysis, these height readings were compared as four-point averages. Alongside the height measurements, the proportions (%) of ground covered by vegetation (live or litter), and bare in the established native warm-season grass stands were also recorded. All dead plant parts found recumbent on the ground surface, including those still attached to the mother plant, were considered litter. As defined in [11], the percentage of material other than bare ground covering the land surface was considered ground cover estimate. These visual estimates of ground cover, based on the vertical projection of above-ground plant parts, for native grass, weeds (all other plants), and litter were recorded a day or two before the first harvest within two randomly placed 1-m^{-2} quadrats. The quadrat area not covered by vegetation was recoded as bare. To ease area estimation, the quadrat-sides were color-painted in alternate 10-cm bands such that a 10 × 10-cm cell represented 1% cover. After about ≥30-cm regrowth following the first harvest, late-summer mean canopy diameter (cm), respective ground cover percentages for native grass, weeds, litter, and bare ground were also recorded.

2.5. Forage Yield Measurements

During the second (2014) and third (2015) June after planting, plots were harvested twice $year^{-1}$ to assess forage biomass production. Harvesting was done using a CIBUS F Plot Forage Harvester (Winterstaiger Ag, Dimmelstrasse, Austria) with a 0.01 kg accuracy weighing system (Juniper Systems, Inc, USA) set to cut at 18 cm above soil surface. From each plot harvest, a representative forage sample was weighed before and after drying at 65˚C in a forced-air oven to a constant weight. The percent moisture content values of samples were used to determine plot DM biomass and yield estimates (kg DM ha^{-1}) were calculated. The same approach was used in estimating forage biomass during the second and third year (Year 2 and Year 3) after planting.

2.6. Data Analysis

The data were subjected to analysis of variance (ANOVA) as a RCBD with a split-plot treatments arrangement having seedling density and species as main- and sub-plots, respectively. Data were analyzed using a computer-based statistical software, the proc GLM, SAS 9.4 [12]. Due to poor and inconsistent germination patterns in the seeded plots, there was not enough data for a credible comparison with those transplanted. During the statistical analyses, therefore, this planting method was excluded from the data set. Data from the transplanted plots was then subjected to analysis of variance (ANOVA) with seedling density and species as fixed effects. Treatment means were compared by the Fisher's Least Significant Difference test at $\alpha = 0.05$. During the data analyses, forage biomass from the first and second cuts were combined into year total yields within respective plot age (years after planting) as Year 2 and Year 3. However, analysis of the measured ground cover attributes was done only for the year of establishment and year 2.

3. Results and Discussion

3.1. Effects of Seedling Density and Species

On the study area, 2013 was a relatively wet year whose summer months experienced high rainfall amounts compared to 2012. While, respective monthly rainfall totals for June and August of 2012 were only about 45 and 66 mm, the same months in 2013 had about 235 mm and 155 mm [10]. These growing conditions were not only favorable for survival of the NWSG seedlings but also more weed challenges. The summaries of ANOVA on forage yield and ground cover attributes of the NWSG stands during the first and second year in production are presented in **Table 1**. Except for the first cut forage yields during the first year and the proportions of ground covered by litter, all other parameters showed no significant species × density interaction at $\alpha = 0.05$. The parameters also showed no significant seedling density effect ($P > 0.05$) although values for the first year total forage yield and ground coverage by liter seemed to be marginally affected ($P = 0.052$). In both harvest years, the species differed in forage yield, sward heights, and cover attributes but not ground cover and line intercept. Likewise, **Table 2** summarizes the ANOVA results on cover attributes of the late-summer regrowth. All parameters studied showed no significant effect of seedling density or density × species interaction (P = 0.5). Species effect was only observed on canopy diameter and the proportion of ground covered by native grass.

3.2. Forage Biomass Production

Results of mid-summer and total forage biomass production recorded during the first harvest-year are summarized in **Table 3**. Due to significant species × density interaction forage biomass (mid-summer and total) during the first harvest-year, respective species means are compared, separately, within each seedling density. During the first and second harvest-years, SG produced greater mid-summer forage biomass compared to the other three species whose means were also statistically similar. However, by late summer of the same year, forage biomass was similar for SG and IG and consistently greater than for GG, but not BB except at the medium seedling density. All other species mean differences were only numerical. Cumulative yields recorded during the first year were consistently greater for SG than BB or GG with the latter also being smaller than

Table 1. Summary of ANOVA tables for effects of seedling density (within-row plant spacing)† and species on forage biomass during the second and third year after planting (Yr1, 2014 & Yr2, 2015), early-spring basal diameter (BDMT), early-summer sward heights, proportions of row segment intercepted (LINT) by native grass crowns, and that of ground covered by vegetation material in native warm-season grass (NG)‡ stands during the second year after planting.

Source	DF‡‡	Pr > F¶												
		First cut		Second cut		Total forage		Cover		Sward	Proportional ground cover			
		Yr1	Yr2	Yr1	Yr2	Yr1	Yr2	BDMT	LINT	height	NG	Weed	Liter	Bare
Density	2	0.101	0.648	0.159	0.547	0.052	0.117	0.946	0.291	0.232	0.605	0.528	0.052	0.558
Species	3	<0.001	0.003	<0.001	<0.001	0.003	<0.001	<0.001	0.660	0.013	0.702	0.017	<0.001	<0.001
Interaction	6	0.042	0.843	0.114	0.999	0.017	0.902	0.943	0.889	0.140	0.939	0.784	0.017	0.989

†At low, medium, and high seedling density, plants within-row were spaced 30-, 25-, and 20-cm apart, approximately 10, 12, and 15 plants m^{-2}, respectively. ‡Big bluestem (*Andropogon gerardii*), eastern gamagrass (*Tripsacum dactyloides*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*). ‡‡Degrees of freedom for the listed source of variation. ¶The probability of two means of the same parameter being significantly different.

Table 2. Summary of ANOVA showing effects of seedling density (within-row plant spacing)† and species on late-summer regrowth canopy diameters, proportion of ground covered by vegetation material and bare patches in native warm-season grass stands‡ during the second year after planting.

Source	DF‡‡	Pr > F¶				
		Canopy spread	Percentage Ground Cover			
		Diameter	Native grass	Weeds	Litter	Bare
Density	2	0.960	0.982	0.354	0.272	0.907
Species	3	0.007	0.001	0.727	0.479	0.243
Interaction	6	0.562	0.624	0.983	0.998	0.901

†At low, medium, and high seedling density, plants within-row were spaced 30-, 25-, and 20-cm apart, approximately 10, 12, and 15 plants m^{-2}, respectively. ‡Big bluestem (*Andropogon gerardii*), eastern gamagras (*Tripsacum dactyloides*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*). ‡‡Degrees of freedom for the listed source of variation. ¶The probability of two means for the same parameter being significantly different.

Table 3. Effects of seedling density (within-row plant spacing)† on forage biomass yield of four native warm-season grasses (BB, *Andropogon gerardii*; GG, *Tripsacum dactyloides*; IG, *Sorghastrum nutans*; SG, *Panicum virgatum*) during the second and third year after planting (2014 & 2015).

Density	Species	Yield by harvest batch‡ and year					
		Mid-summer		Late-summer		Cumulative	
		Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
		kg DM ha^{-1}					
HIGH	**BB**	1372b‡‡	2150b	4987bc	3146b	6360b	5296b
	GG	896b	2708b	4029c	2729b	4925c	5436b
	IG	1380b	2516b	8770ab	4977a	10,151ab	7493ab
	SG	5411a	4038a	12,834a	3762ab	18,245a	7799a
	Pr > *α*¶	<0.001	0.043	0.005	0.082	<0.001	0.071
MEDM	**BB**	1311b	2560b	4922b	2854bc	6233b	5414
	GG	1062b	2957ab	3906b	2135c	4969b	5092
	IG	1455b	2517b	9507a	4682a	10,961a	7199
	SG	4167a	3565a	8707a	3528ab	12,874a	7093
	Pr > *α*	0.003	0.439	<0.001	0.011	0.001	0.146
LOW	**BB**	1480b	2588ab	5316bc	2827b	6796bc	5415ab
	GG	794b	2260b	4108c	2239b	4901c	4500b
	IG	1357b	2346b	7769a	4755a	9126ab	7102a
	SG	3113a	3357a	7574ab	3373ab	10,686a	6730a
	Pr > *α*	<0.001	0.126	0.011	0.031	0.002	0.082

†At low, medium (MEDM), and high seedling density, plants within-row were spaced 30-, 25-, and 20-cm apart, approximately 10, 12, and 15 plants m^{-2}, respectively. ‡Mid- and later-summer harvests were recorded in June and August, respectively. ‡‡Within a column and for same seedling density, species means followed by the same letter are not significantly different at $\alpha = 0.05$. ¶The probability of two means for the same parameter being significantly different.

IG. Cumulative forage biomass, across the three seedling densities, averaged nearly 14,000 and 10,000 kg DM ha^{-1} for SG and IG, respectively, both being greater than the average of about 5700 kg DM ha^{-1} for BB and GG.

Even with no significant treatment effect on the forage biomass, the values for SG tended to be in the order High > Medium > Low density. The trend was somewhat consistent with reported greater forage biomass at higher than lower plant densities for corn [13] and GG during the establishment [14]. In the current study, however, the within-row plant spacing was probably too close to allow enough room for crown expansion. While plants in the study by [14] were spaced ≥30 cm apart (45 cm row spacing), equivalent to nearly 9 plants m^{-2}, those in the current study were ≤30 cm apart or 10 - 15 plants m^{-2}. The lack of seedling density effect on yield is in agreement with reported findings for transplanted BB stands [15] whose forage biomass peaked at 5.4 plants m^{-2} and remained constant through 10.8 plants m^{-2}. To some extent, this lack of treatment effect was attributable to the tendency for the wider-spaced clumps to have thicker stems and bigger crowns than their close-spaced counterparts. This might have allowed for the observed gap-filling abilities of the sparsely-spaced NWSG clumps to compensate for the differences in individual plant performance. Furthermore, although the close-spaced clumps still retained significant inter-row spaces for expansion, their swards tended to have fewer and weaker weed plants (field observations). Still, the gap-filling effect of weeds seemed more on the mid-summer regrowth since even the second harvest species yield differences were either not significant or only marginal.

3.3. Basal Ground Cover

The results summarized in **Table 4** show how the treatments affected expansion of the native grass stubbles, based on basal diameter and within-row line intercept data. There being no significant species × density interaction effect on the recorded basal diameter, line intercept, or sward heights (**Figure 1**), species means have been pooled across seedling densities. Of the four native grass species, GG had the greatest early-spring basal diameters (26 cm) but, not statistically different ($P < 0.01$) from IG (24). The least mean basal diameter (18 cm) was for BB although not significantly different from the 21 cm for SG. Within-row, line intercepts were similar for GG (60) and SG (59) than both BB and IG that averaged 48 ($P < 0.01$). The same ranking was observed on the mid-summer sward heights, which ranged from 41 to 54 cm.

In the native grass stands, mid-summer canopy diameter also showed no treatment difference and proportional cover estimates averaged about 60% (**Table 4**). The cover by weeds (all other plants) were the least in GG (13%) although only statistically different from SG ($P < 0.02$) and at least twice as much ground surface was covered by litter (27%). The cover values for liter showed no species difference and averaged about 19% while the percentage bare ground was only about 5% in SG, exceeding the three folds the 1.5 average for the other species.

Table 4. Effects of species (BB, *Andropogon gerardii*; GG, *Tripsacum dactyloides*; IG, *Sorghastrum nutans*; SG, *Panicum virgatum*) pooled across seedling densities (within-row plant spacing)† on early-spring basal cover‡, mid-summer sward-heights‡‡, and proportions of ground covered by live vegetation, litter, or left bare in the native warm-season grass stands recorded during the second year after planting.

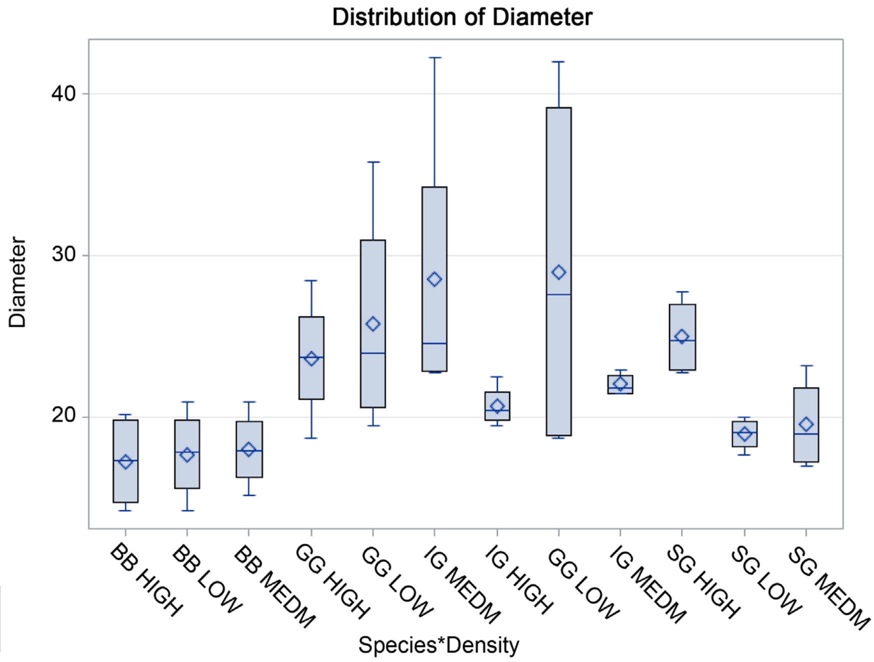
Species	Cover		Sward Height	Proportional ground cover			
	Basal diameter	Line intercept		Native grass	Weeds	Liter	Bare
	---cm---	----%----	----cm---	----------------------%-------------------			
BB	18c¶	48b	42b	63	18ab	20	0.6b
GG	26a	60a	54a	62	13b	21	1.7b
IG	24ab	46b	41b	61	19ab	20	2.1b
SG	21bc	59a	49a	56	27a	15	4.8a
Pr > α§	0.003	<0.001	<0.001	0.66	0.013	0.702	0.017

†At low, medium, and high seedling density, plants within-rows were spaced 30-, 25-, and 20-cm apart, about 10, 12, and 15 plants m^{-2}, respectively, but with no effect on the cover attributes. ‡Averaged six-point estimates of proportions of three alternate 1-m inner-row segments spaced ≥60-cm apart that were intercepted by the native grass stems at about 2.5 cm stubble-height. ‡‡Three-point average of the heights at which a meter stick held horizontally above the sward touched at least two tallest leaves on separate rows. ¶Within a column, means followed by the same letter, lowercase for means under the same seedling density or uppercase for same species across densities are not significantly different at $\alpha = 0.05$. §The probability of two species means for the same seedling density being significantly different.

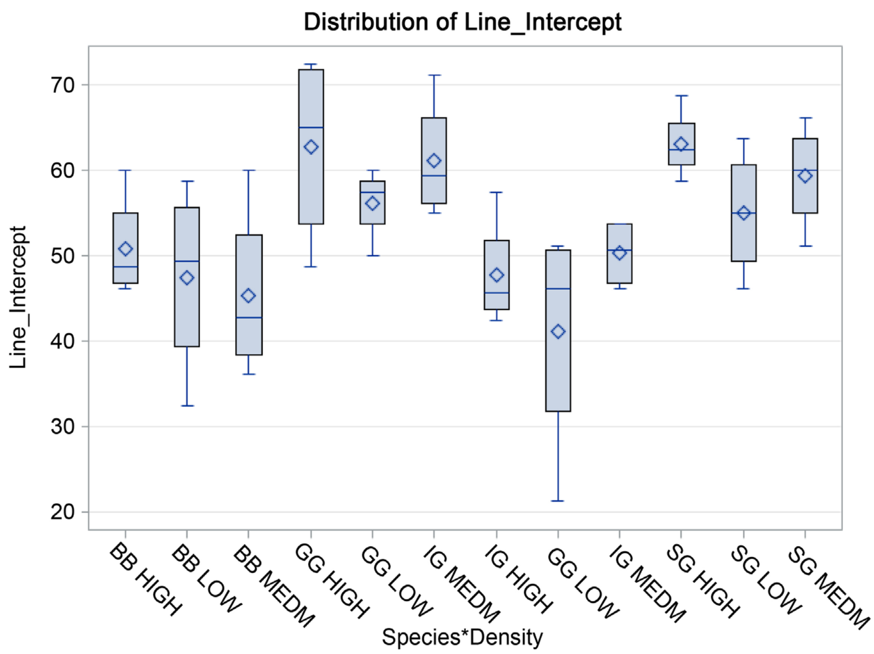
This lack of wide variations in the measured cover attributes demonstrate a desirable ability of transplanted NWSGs to quickly establish thick stands and suppress the growth of weeds. Based on the fact that basal diameters of the NWSGs were only ≤ 26 cm, weeds suppression was mostly attributable to their stand structure; characterized by canopies that are much wider than their crowns. It is, therefore, important that defoliation be managed to favor faster regrowth and canopy closure, thus keeping weeds from outgrowing the recovering perennials. These differences may, therefore, be more attributable to species potential rather than their comparative tolerance to defoliation.

3.4. Species Sward Structure

The treatment responses in late-summer canopy diameters and proportional ground cover values showed no significant species × density interaction (**Table 5**). Species comparison for these parameters was, therefore, based on means pooled across seedling densities. For the canopy diameter, GG had greater (57 cm) values ($P < 0.01$) than both BB (47 cm) and SG (51 cm) but similar to that of IG (54 cm). Of the four NWSG species, GG had the greatest mean percentage ground cover value (52), although not significantly different from that of IG (45). The least ground cover value was for BB (36) but statistically similar to SG (41). Additionally, the proportions of bare ground, that was covered by weeds and litter showed no species difference and averaged about 14%, 38%, and 4%, respectively. These similarities in the assessed cover attributes among the native



(a)



(b)

Figure 1. Effects of seedling density (based on 30-, 25-, and 20-cm within-row spacing) and species (BB, *Andropogon gerardii*; GG, *Tripsacum dactyloides*; IG, *Sorghastrum nutans*; SG, *Panicum virgatum*) on ground cover as indicated by (a) mean spring basal diameter and (b) the length of 1-m row segments intercepted by crowns of native warm-season grasses during the second year after planting. MEDM = medium.

grasses recovering from common defoliation events suggest that their usefulness as summer wildlife habitat is most likely as food rather than shelter. Their reliability as wildlife feed resources will still depend on the proportions of desirable

Table 5. Species effects on late-summer canopy diameter†, the proportions of ground covered by plant material, and that of bare patches, pooled across three seedling densities‡, in native warm-season grass (BB, *Andropogon gerardii*; GG, *Tripsacum dactyloides*; IG, *Sorghastrum nutans*; SG, *Panicum virgatum*) stands during the second year after planting.

Species	Canopy Diameter	Proportional ground cover			
		Native Grass	Weeds	Litter	Bare
	---cm---	---------------------------%-----------------------------			
BB	47.2c‡‡	36c	19	42	3
GG	57.5a	52a	12	33	3
IG	54.7ab	45ab	14	38	3
SG	51.0bc	41bc	12	41	6
Pr > α§	0.007	0.001	0.727	0.479	0.243

†Average of six readings at about 2.5 cm stubble-height from three alternate 1-m inner-row segments spaced ≥ 60-cm apart. ‡At low, medium, and high seedling density, plant spacing was 30-, 25-, and 20-cm, within-row, giving approximately 10, 12, and 15 plants m^{-2}, respectively. ‡‡Within a column, means followed by the same letter are not significantly different at $\alpha = 0.05$. §The probability of two species means for the same seedling density being significantly different.

species in the weed population and how that may influence the abundancy of insects in the stands. Wildlife feed availability may vary with the actual litter biomass present due to its effects on soil moisture retention and invertebrate populations as previously reported [16] [17].

4. Conclusion

These results show that transplanting BB, GG, IG or SG, reducing the plant density from 15 to 10 seedlings m^{-2} does not have significant effect on the early-stand forage biomass production. While, in year 2, the forage biomass for SG was similar to IG and consistently greater than BB and GG, yields in year 3 remained more or less stable for the latter pair but decreased notably for the other. This implies that transplanting SG or IG at <30 cm within-row plant spacing or >10 seedlings m^{-2} to increase early stand forage biomass may not be economical since the resulting yield differences may only be short lived. Data also show that reducing the NWSG transplant at seedling density from 15 to 10 plants m^{-2} may not result in any significant difference in wildlife habitat quality features associated with sward structure. However, because of morphological species differences, desirable wildlife habitat qualities in mixed stands may be enhanced by strategically adjusting seedling proportions at planting. The data also show that, when transplanting NWSGs, reducing the plant density from 15 to 10 seedlings m^{-2} may not have significant implication on weeds challenge during the stand establishment phase. Information on how combined effects of spatial patterns and seedling density influence establishment success and early performance of transplanted NWSGs is needed to support rational management decisions in NWSGs forage systems.

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