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RESEARCH

Dormant-Season Planting and Seed-Dormancy Impacts on Switchgrass Establishment and Yield

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ABSTRACT

Establishment failures linked to seed dormancy are a challenge to wide-scale use of switchgrass (*Panicum virgatum* L.) for biomass feedstock and forage production. One prospective strategy for breaking dormancy is dormant-season planting. The objectives of this study were to evaluate (i) three switchgrass dormant-season planting dates (1 December, 1 February, and 15 March) vs. a growing-season (1 May) control; (ii) two seeding rates (6.7 and 10.1 kg pure live seed [PLS] ha^{-1}); and (iii) high- and low-dormancy seed lots. Treatments were assigned in a split-plot design with three replications at two locations in Tennessee in 2008 and 2009. Neither seeding rate nor seed-dormancy level affected plant density or yield ($P > 0.05$). However, a seeding date × year interaction impacted first-year density at both locations. Although patterns differed by year for the two locations, density of March plantings equaled or exceeded ($P < 0.05$) those at other dates for both locations and years. These variations in density did not carry over to impact yield in year two. A sigmoidal regression of seedling density vs. yield was significant ($P < 0.001$) albeit not strong ($R^2 = 0.13$); yield response approached an asymptote above ~8 plants m^{-2}. Results suggest March planting dates, using standard seeding rate recommendations (6.7 kg PLS ha^{-1}) irrespective of seed-dormancy rates, may be more reliable than planting in May. Thus, a broader establishment window than traditionally used may be practical. However, results should be validated over a broader range of soils and climatic conditions, especially over a winter severity gradient.

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Abbreviations: ETREC, East Tennessee Research and Education Center; HRREC, Highland Rim Research and Education Center; PLS, pure live seed; Trmt, seeding treatment.

Switchgrass, a C_4 grass native to eastern North America, has much promise as a bioenergy (Sanderson et al., 1996; McLaughlin and Kszos, 2005) and forage crop (Anderson and Matches, 1983; Burns and Fisher, 2013) and, more recently, has been considered in dual-use, forage–biomass systems (Guretzky et al., 2011, Mosali et al., 2013). However, difficulty in establishment may create substantial obstacles to its wide-scale use by producers (Panciera and Jung, 1984; Aiken and Springer, 1995; Parrish and Fike, 2005). Establishment failures penalize producers through additional expenses for seedbed preparation, seed, as well as indirectly through lost production. Not only do establishment failures have economic consequences, but they may also discourage other producers from attempting to use switchgrass despite its benefits.

Although past research on improving establishment success of switchgrass has included examinations of seed size (Aiken and Springer, 1995; Smart and Moser, 1999), seeding depth (Berti and Johnson, 2013), and competition control (McKenna et al., 1991; Curran et al., 2011), most workers have focused on seed dormancy (Shen et al., 2001; Beckman et al., 1993; Haynes et al., 1997) and

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planting dates (Panciera and Jung, 1984; Hsu and Nelson, 1986a,b; Smart and Moser, 1997; Foster et al., 2013). Seed dormancy has been well documented in switchgrass (Parrish and Fike, 2005; Sanderson et al., 2012) and is thought to be a common cause of establishment failures; up to 2 yr of after ripening may be required for this species to become germinable (Burson et al., 2009). Substantial improvements in germination and initial stand success have resulted from breaking seed dormancy through cold stratification (Zarnstorff et al., 1994; Shen et al., 2001). Conversely, breaking dormancy through chemicals, growth regulators, and mechanical methods has proven to be less effective (Jensen and Boe, 1991; Zarnstorff et al., 1994). Past recommendations for cold stratification have involved soaking, draining, and then chilling seed in a cooler, all of which can be problematic for producers and emphasize the need to find simple, practical approaches for reducing dormancy (Wolf and Fiske, 1995; Parrish and Fike, 2005).

Planting date also impacts establishment success. Earlier stand initiation can lead to better initial growth, improved yield (Vassey et al., 1985), and possibly better drought tolerance as a result of the more advanced stage of development attained by seedlings as they enter summer (Hsu and Nelson, 1986b; Smart and Moser, 1997). Timing of emergence may also allow seedlings to be more competitive with weeds (Hsu and Nelson, 1986b; Foster et al., 2013). This is important because weed competition has been shown to be a serious challenge in switchgrass establishment (Boydston et al., 2010; Curran et al., 2011; Miesel et al., 2012).

However, studies of seeding dates have mainly reported results from growing-season plantings and not from those during the dormant season (Panciera and Jung, 1984; Vassey et al., 1985; Hsu and Nelson, 1986a; West and Kincer, 2011). Smart and Moser (1997) included a single, dormant-season date (March) in their Nebraska study, which resulted in substantial in situ stratification suggesting this could be an effective strategy for improving germination. Sanderson et al. (1996) reported similar in situ stratification resulting from early April plantings in southwest Virginia. In a second Great Plains study, Foster et al. (2013) also evaluated February plantings and reported improved yields vs. traditional May plantings.

Despite the potential benefits from dormant-season planting of switchgrass, the approach has not been well studied and several factors must be considered before developing effective methods. First, because of the increased potential for seed loss through the winter, increased seeding rates may be required for successful stand establishment (Vassey et al., 1985; Foster et al., 2013). Second, if loss rates are high enough with low dormancy seed, it may not be practical to use such seed lots for dormant-season planting; instead, those with high dormancy rates would be required (Sanderson et al., 1996). Finally, a range of dormant-season planting dates has not been investigated. Smart and Moser (1997) and Foster et al. (2013) each only included a single planting date (March and February, respectively) within the dormant season and did not consider earlier dormant-season dates (e.g., December). Given that seed shattering for switchgrass occurs in autumn and certainly by early winter, it may be that those dates earlier in the winter are preferable for switchgrass establishment. However, planting earlier in the winter has not been investigated. Therefore, an experiment was implemented to further examine dormant-season planting of switchgrass. Specifically, the objectives were to evaluate stand density and yield based on (i) three dormant-season planting dates vs. a growing-season control, (ii) recommended and increased seeding rates, and (iii) high and low seed-dormancy levels.

MATERIALS AND METHODS

Site Description

The study was conducted at two locations: Highland Rim Research and Education Center (HRREC; 35.5° N, −87.3° W) on a soil mapped Mountview silt loam (fine-silty, siliceous, semiactive, thermic Oxyaquic Paleudults) and East Tennessee Research and Education Center (ETREC; 35.53° N, −83.6° W) on a Corryton-townley complex (fine, mixed, semiactive, thermic Typic Hapludults) soil. Based on annual soil tests from 0- to 15-cm depths (Mehlich-1), levels of P (62 ± 20.3 kg ha^{-1}) and K (240 ± 67.7 kg ha^{-1}) and pH (mean = 6.7; range 6.0–7.7), these were not amended during the course of the study.

Experimental Design

Four planting dates (1 December, 1 February, 15 March, and 1 May) and four seeding treatment levels (high seeding rate and high dormancy, high seeding rate and low dormancy, low seeding rate and high dormancy, and low seeding rate and low dormancy) were assigned in a randomized complete block with treatments arranged in split blocks. Planting dates were assigned the whole plot and the four seeding treatment levels were split plots. Blocking occurred on soil–slope position with three replicates (n = 48 plots) at each location. The experiment was initiated in December 2008 and repeated beginning in December 2009. Plots established in December 2009 through May 2010 were located in a different area than those established in the previous year to ensure that no dormant seed from the first planting emerged during 2010 and confounded results.

Switchgrass field plots (1.5 by 7.6 m) were established with a no-till Hege plot drill (Hege Equipment, Inc.). 'Alamo' switchgrass was planted at high or low seeding rate with either high or low dormancy seed levels in 2008 and 2009, respectively. All seed was provided by a single commercial grower (Ernst Conservation Seeds, Inc.) with dormancy confirmed by laboratory test at 45% (Lot WB-DAS-07-2) and 2% (Lot WV-07-MV-1) for Year 1 seedings (December 2008–May 2009) and 75% (Lot N385) and 5% (Lot N384) for Year 2 seedings (December 2009–May 2010). All seed was stored in a cooler at 4°C until planting. Standard recommended seeding rates (1× rate) for switchgrass are 6.7 kg PLS ha^{-1} (Garland, 2008; Keyser et al., 2012), making that a logical seeding rate to test in this experiment. Because of the risk of seed loss during dormant-season seeding (Vassey et al., 1985; Sanderson et al., 1996; Foster et al., 2013), a greater rate (1.5× rate, 10.1 kg PLS ha^{-1}) was also included in the experiment. Planting depth were 0.6 to 1.3 cm with 18-cm row spacing.

All plots were sprayed before planting with paraquat [1, 1'-dimethyl-4,4'-bipyridinium] at a rate of 0.56 kg a.i. ha^{-1} between 20 February and 10 March and then with glyphosate {[*N*-(phosphonomethyl) glycine]; 2.25 kg a.i. ha^{-1}} between 5 and 15 April per experimental year. Glyphosate treatments were applied before soil temperatures exceeded 15.6°C each year to control cool-season weeds before seedling emergence. Second-year switchgrass stands received a single application of 67 kg N ha^{-1} in the form of ammonium nitrate (NH_4NO_3) when stands were approximately 30 cm tall (~15 April). Aside from N fertilization, no other macronutrient was applied during the course of the study. Switchgrass stands were not disturbed during the growing season and no postemergent herbicides were applied.

Data Collection

Daily precipitation and temperature data were collected on site at each location. Switchgrass plant density measurements were determined at the end of the first growing season (typically, late October) annually using a 0.75-m^2 density grid (Vogel and Masters, 2001). Four frequency counts were randomly taken (n = 4) on each treatment plot and averaged on a per-plot basis. First-year stands had considerable weed pressure and, therefore, were not harvested for biomass yield. After the second growing season, plots were harvested postsenescence (between 15 October and 1 November during 2010 and 2011) to estimate biomass yield using a Carter harvester (Carter Manufacturing) with a 91-cm cutting width to a 20.3-cm stubble height. Grab samples of switchgrass (1–2 kg) were collected from all plots at harvest, weighed, dried at 49°C in a batch oven (Wisconsin Oven Corporation) and weighed again to determine moisture content.

Data Analysis

Switchgrass yield and density data were analyzed under an ANOVA model using the PROC MIXED procedures of SAS (SAS Institute, 2007), with seeding treatment (Trmt), planting date (Date), location (Loc; HRREC and ETREC), and year (Year; one [December 2008–May 2009] and two [December 2009–May 2010]) as fixed effects, and block entered into the model as a random effect. Interactions of Trmt, Date, Loc, and Year were also entered into this model. Thus, all data for both locations and both years were analyzed under a single, global model. Based on that model, there was a three-way interaction with Loc, Year, and Date for plant density (F = 13.92; P < 0.001) as well as for yield (F = 3.35; P = 0.02). Therefore, subsequent models were run by Loc and included Year, Trmt, and Date as main effects, and the interactions of those factors. Mean separation was performed for significant model terms using Fisher's LSD with P < 0.05. Response variables were tested for normality using SAS Proc UNIVARIATE (SAS Institute, 2007). Homoscedasticity of variances was tested using Bartlett's test in SAS, Proc MIXED (Zar, 2009). All variables met assumptions of normality and homoscedasticity, and no transformations were made.

To further understand the relationship between switchgrass density and yield, a regression model was developed using polynomial, linear regression in SigmaPlot (V12.5; SigmaPlot, 2006). Independent (plant m^{-2} in Year 1) and dependent (Mg ha^{-1} in Year 2) variables were based on per-plot (n = 48 per year × location combinations, 192 total) means drawn from this study. To increase sample size and broaden model inferences, data from a comparable set of plots (n = 45 per 2-yr-by-three-location combinations, or 270 total) installed as a part of a related switchgrass establishment experiment at the same two sites (HRREC and ETREC) plus a third site (Milan Research and Education Center, Milan, TN) during the same 2 yr was included in the model (unpublished data, 2012). Plot layout, establishment protocols (i.e., no-till drilling), harvest timing, and switchgrass variety from this second study were the same as those used in the current experiment. Because of damage to plots in 1 yr at one location in the second study, 15 plots were removed, leaving 447 that were used in the analysis. Data from the two experiments were pooled and regressed on a per-observation basis (i.e., plot; per x [density], y [yield] variable) on 2-yr-old stands in 2010 and 2011. All observations were normally distributed ($P \geq 0.05$; normality test, Shapiro–Wilk = 0.97).

RESULTS

Weather conditions during the experimental establishment windows for both years varied by year and location. At HRREC during 2009, precipitation was below the 30-yr mean in February and March and above the 30-yr mean in May and June (Fig. 1a). In 2010, conditions were drier, with February, March, April, June, and July all below and May above 30-yr precipitation normals. In 2009 at HRREC, temperatures remained very close to the long-term average, but during 2010, conditions were more extreme, with winter temperatures below average and those from April through September all above average (Fig. 1b). At ETREC, precipitation during 2009 remained near the long-term average except during January, May, and July, when it exceeded those averages (Fig. 2a). During 2010, however, precipitation at ETREC during summer months (June, July, and August) was below average. Temperatures at ETREC followed a very similar pattern to those at HRREC, near normal in 2009 and well above average during summer 2010 (Fig. 2b).

At HRREC, Date (F = 4.14, P < 0.01) and Year (F = 65.13, P < 0.001) influenced plant density, but Trmt did not (F = 1.93, P = 0.10; Table 1). Among interactions, only Date × Year was significant (Table 1). During 2009, the lowest densities were associated with December and February, and the greatest with March planting; those in May did not differ from the other three dates (Fig. 3a). On the other hand, in 2010, switchgrass density resulting from planting dates in December, February, and March did not differ from one another, but all were greater than those recorded in May (P > 0.05). Excluding May planting dates, 2010 switchgrass densities at HRREC exceeded those for 2009.

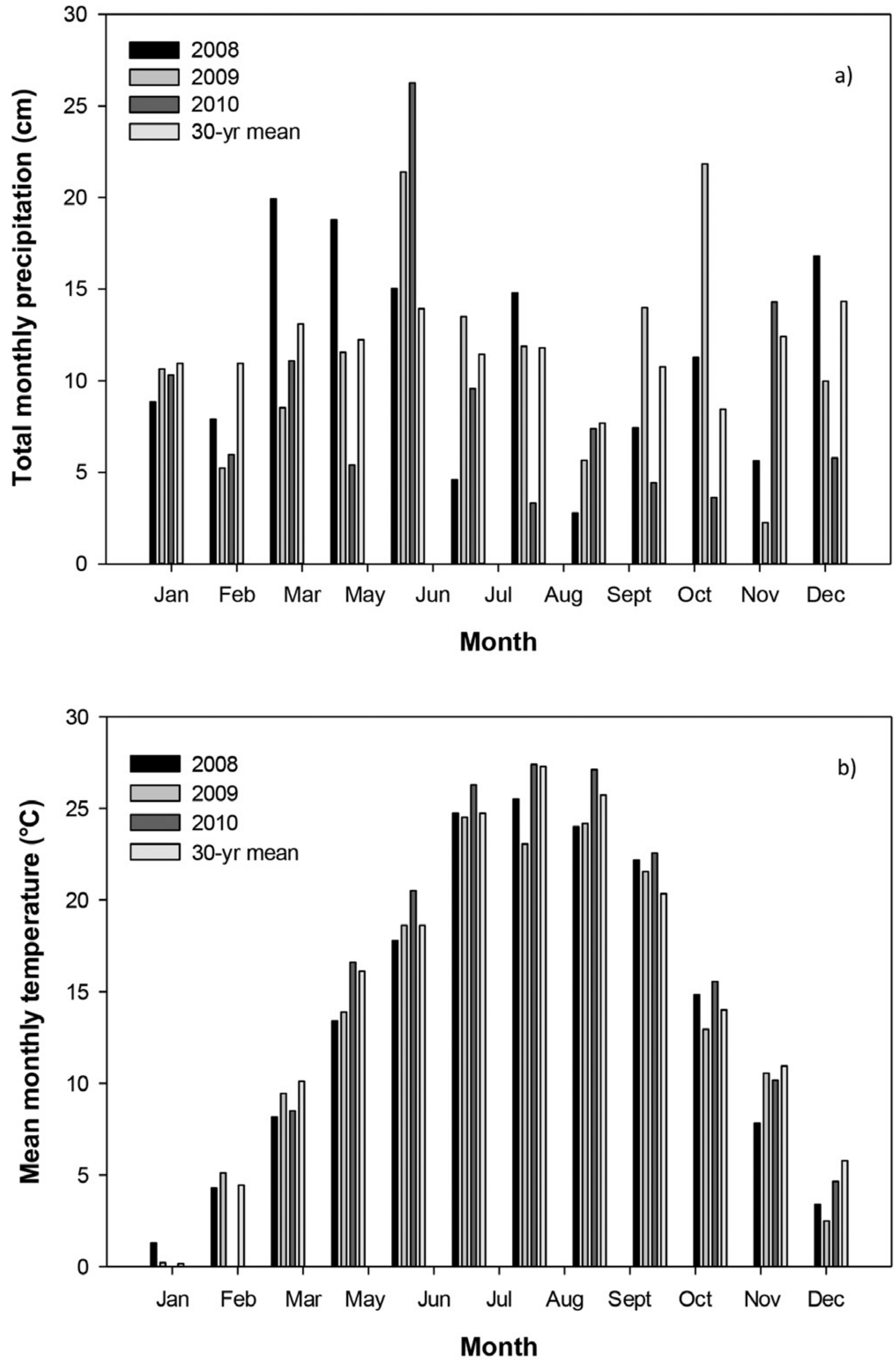


Figure 1. (a) Total monthly and normal precipitation and (b) mean monthly and normal temperature at Highland Rim Research and Education Center, Springhill, TN, 2008 through 2010. Normal precipitation and temperature data (1981–2010) were taken at the research center and obtained from US National Oceanic and Atmospheric Administration (NOAA; NOAA, 2013).

Despite initial differences in plant density, there were no differences for any of the main effects or interactions for dry matter yield at HRREC in second-year stands (Table 1). For all treatment levels, yields were between 3.5 and 5.0 Mg ha^{-1} (Fig. 3b).

At ETREC, responses for switchgrass plant density were similar to those observed at HRREC, with significant relationships for Date ($F = 4.26$, $P < 0.01$) and Year ($F = 19.09$, $P < 0.001$), but not for Trmt ($F = 1.52$, $P = 0.21$; Table 1). Likewise, only the interaction for Date × Year was significant (Table 1). Within-year patterns for plant density were fairly similar at ETREC to those observed at HRREC except that the years in which those patterns were observed were opposite (Fig. 4a). In 2009,

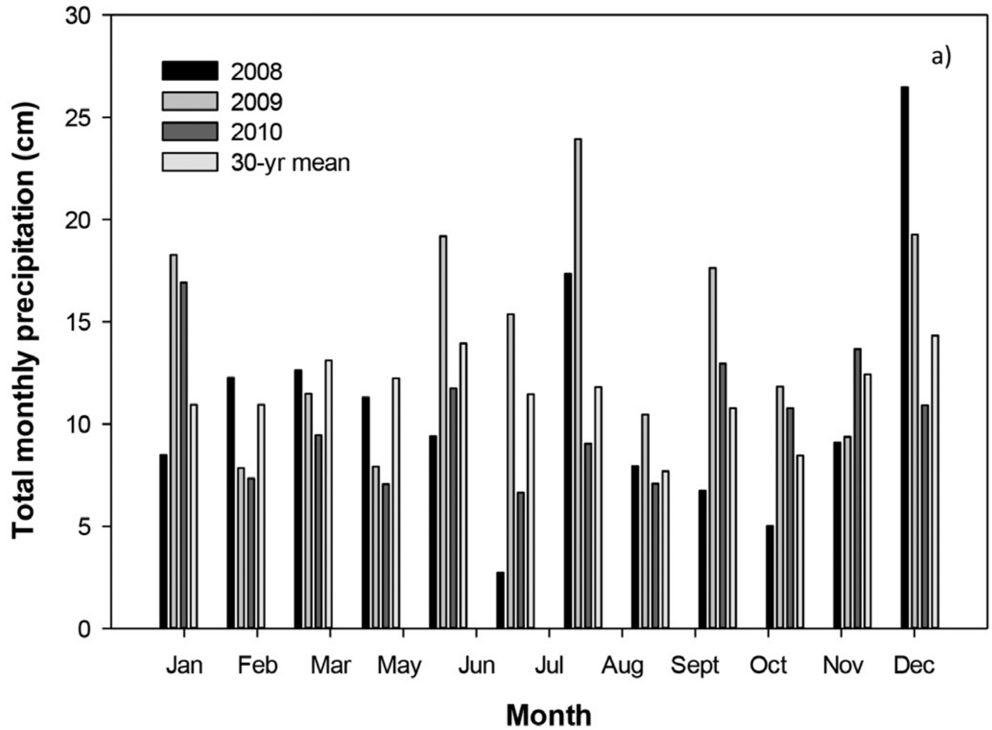


Figure 2. (a) Total monthly and normal precipitation and (b) mean monthly and normal temperature at East Tennessee Research and Education Center, Knoxville, TN, 2008 through 2010. Normal precipitation and temperature data (1981–2010) were taken at the research center and obtained from the US National Oceanic and Atmospheric Administration (NOAA; NOAA, 2013).

the greatest densities were observed for December, February, and March planting dates, and these did not differ from one another but all were greater than those recorded in May. In 2010, plant densities for March exceeded those in February but were not different from those in December; those in May did not differ from the other three dates ($P > 0.05$). Densities associated with earlier plantings in 2009 exceeded those observed in 2010, but the latter two dates were not different between years ($P > 0.05$). Thus, for both locations, albeit in different years, the greatest densities resulted from dormant-season plantings.

As was the case at HRREC, dry matter yields in second-year stands did not have relationships with any main effects despite differences in initial (first year) plant

Table 1. Analysis of variance results for dormant-season switchgrass establishment study conducted at Highland Rim and East Tennessee Research and Education Centers in Spring Hill (HRREC and ETREC, respectively), Knoxville, TN, 2009 and 2010.

Dependent variable	Source	df	HRREC		ETREC	
			F	*P* > *F*	*F*	*P* > *F*
Density	Date†	3	4.14	0.009*	4.26	0.008*
	Treatment‡	3	1.93	0.103	1.52	0.217
	Year§	1	65.13	<0.001*	19.09	<0.001*
	Date × treatment	9	1.17	0.426	0.67	0.730
	Date × year	3	8.82	<0.001*	10.22	<0.001*
	Treatment × year	3	2.14	0.103	0.28	0.829
Yield	Date	3	1.28	0.293	2.12	0.097
	Treatment	3	1.20	0.362	0.86	0.557
	Year	1	1.37	0.353	0.43	0.445
	Date × treatment	9	1.18	0.252	0.52	0.831
	Date × year	3	1.78	0.512	2.54	0.064
	Treatment × year	3	2.15	0.103	0.28	0.838

* Significant at the 0.05 probability level.

† Planting date: 1 December, 1 February, 15 March, and 1 May.

‡ Treatment: High seeding rate and high dormancy, high seeding rate and low dormancy, low seeding rate and high dormancy, low seeding rate and low dormancy.

§ Establishment year: one (December 2008–May 2009) or two (December 2009–May 2010).

densities (Table 1). However, one interaction, Date × Year, appeared to show a trend ($F = 2.54$, $P = 0.06$) that mimicked that for switchgrass density. In this case, there was no difference in yields between years for any planting date, but December 2010 yields were less than those for February and May (Fig. 4b). Overall yields, except for December 2010, were somewhat greater than those observed at HRREC, that is, between 4.2 and 6.6 Mg ha^{-1}.

Regressing yield on density demonstrated a sigmoidal, (sigmoid, three parameter) relationship between these two variables ($R^2 = 0.128$, $P < 0.001$; Fig. 5) of the form yield $= a/\{1 + \exp[-(\text{density} - x0)/b\}$ with parameter (SE) estimates of $a = 7.25 \pm 0.28$ ($P < 0.001$), $b = 2.98 \pm 0.81$ ($P < 0.001$), and $x0 = -0.28 \pm 0.603$ ($P = 0.65$). Tests (Shapiro–Wilk) of residuals (W = 0.97; $P < 0.001$) indicated residuals conformed to assumptions of normality.

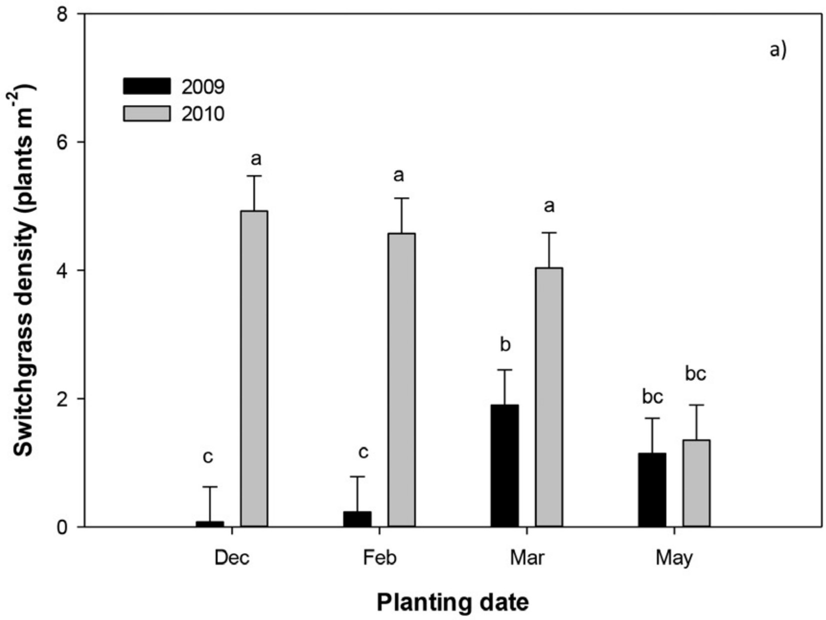
DISCUSSION

Our results suggest that based on Year 2 yields, there is no advantage of dormant-season plantings. On the other hand, these same results also suggest there is no liability associated with dormant-season planting. Conversely, plant density was greater as a result of dormant-season planting in two of four year × location combinations (HRREC 2010 and ETREC 2009), less in one (HRREC 2009), and not different in the fourth (ETREC 2010). Therefore, dormant-season planting may be more consistent with respect to initial stand density. Plantings for March were always equal to or greater to any other date with respect to plant density in all four year × location combinations. Neither seeding rate nor seed-dormancy level at the time of planting influenced initial density or second-year stand yields.

Year of planting was important at both locations for density and may have had some influence on yield at ETREC, suggesting that weather or other factors may have contributed to establishment success. Precipitation during the 5-mo planting window (1 December–1 May) was generally consistent between years (if not between locations) suggesting that it was not a major factor in planting success. There may have been more fine-scale precipitation patterns not evident from the monthly averages, with some planting dates being associated with wetter or drier soil conditions depending on the number of days since rainfall. Regardless, during peak seedling emergence (late April–late May), rainfall patterns provided ample moisture for germination at both locations in both years. With respect to winter temperatures, patterns were virtually identical at the two locations for both years, again suggesting that this was not a causative factor for varying establishment success. Mean monthly low temperatures through March for both locations over both years were <3.8°C, a level more than adequate to allow for cold stratification in all cases (Beckman et al., 1993; Shen et al., 2001).

Weather patterns in the growing season, however, may have been more influential. At HRREC, a drier-than-normal growing season during 2010 (April, June, July, and August) may have reduced weed pressure during the early stages of stand development. At ETREC, substantial drought during 2010 may have negatively impacted stand development.

Weed competition has been demonstrated to be an important factor in switchgrass establishment (Martin et al., 1982; Miesel et al., 2012; Foster et al., 2013). In our case, weeds were abundant during the establishment year, enough so to preclude a harvest that year. The April glyphosate treatments were effective, but warm-season annual grasses were able to become established during May and, especially, June each year. During 2009, density counts were initially conducted on weeds, but because density was routinely at or near 100%, those counts were discontinued. Similarly, West and Kincer (2011) reported substantial impacts to yield associated with poor weed control resulting from warm-season weeds that became established following April weed control. We believe that the development of weeds, especially annual grasses, in our plots was influenced by precipitation patterns and may explain much of the variation observed in establishment success. The April weed treatment we applied was likely essential to switchgrass emergence but proved inadequate at suppressing postemergent weeds. However, that is not a problem that would be unique to dormant-season planting dates. Even with more traditional establishment dates in May, postemergent weed control that addresses annual grasses remains a challenge.



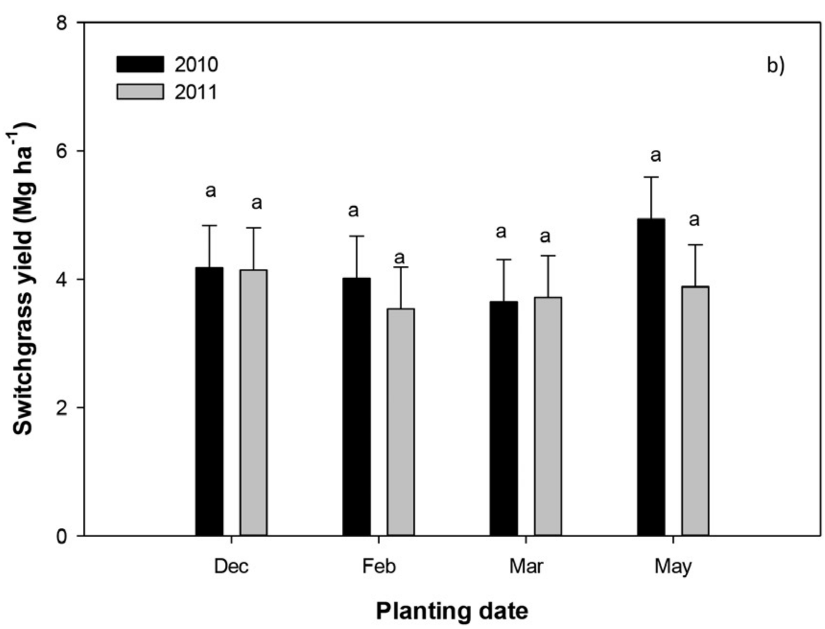
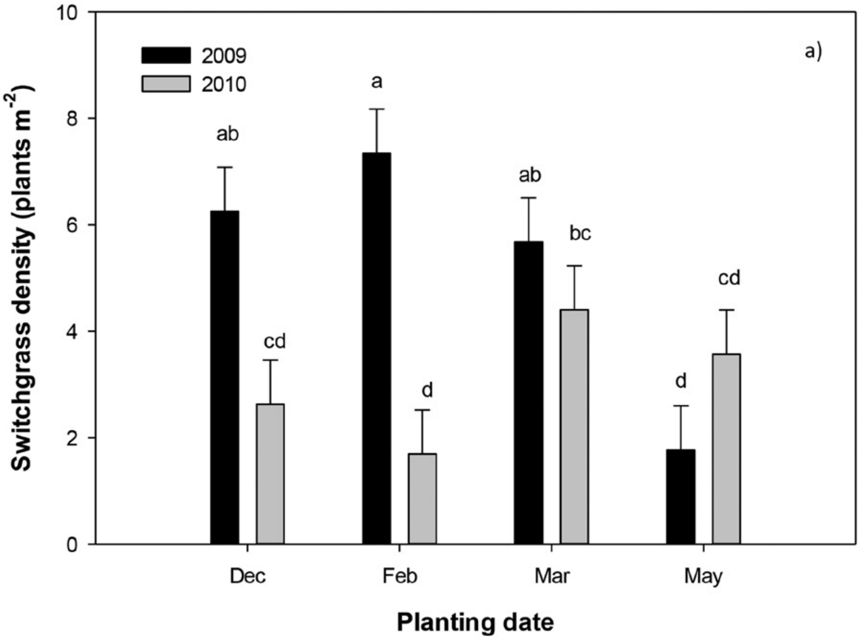


Figure 3. Mean (LS means) switchgrass (a) seedling year plant density and (b) mean (LS means) second year, dry matter yield by each of four planting dates (1 December, 1 February, 15 March, and 1 May) during a dormant-season-establishment study conducted at Highland Rim Research and Education Center, Springfield, TN, 2009 through 2010. Yields were based on dormant-season harvests (15 October–1 November) taken in 2010 from 2008 to 2009 plantings and in 2011 from 2009 to 2010 plantings. Different letters indicate a significant difference ($P \leq 0.05$, LSD = 1.89 and $P \leq 0.05$, LSD = 2.33 for a and b, respectively). Vertical bars are ± one standard deviation.

The density variations we observed were not apparent in yield results. However, other workers (Vassey et al., 1985) have also reported less sensitivity in yield than in density when working with switchgrass and concluded that tillering during the second year compensated for lower density stands. Indeed, Sanderson and Reed (2000) demonstrated a strong inverse relationship between plant density and tiller count per plant. Our regression model reflected consistent yields (within 7.3% of the asymptote) above ~8 plants m^{-2}, indicating either a biological threshold or a compensatory growth pattern. Likewise, Schmer et al. (2006) reported a threshold above which yields were less sensitive to plant density.

Lack of influence from either seeding rate or dormancy levels indicates that any seedlot could be used for dormant-season planting. Apparently, any seed loss that did occur did not exceed the difference in the seeding rates used here (1× vs. 1.5×). With respect to dormancy, either enough cold stratification occurred naturally (Smart and Moser, 1997) or initial dormancy, at the levels tested, was not an issue. Failed seedings of switchgrass that have been attributed to dormancy may have been the result of



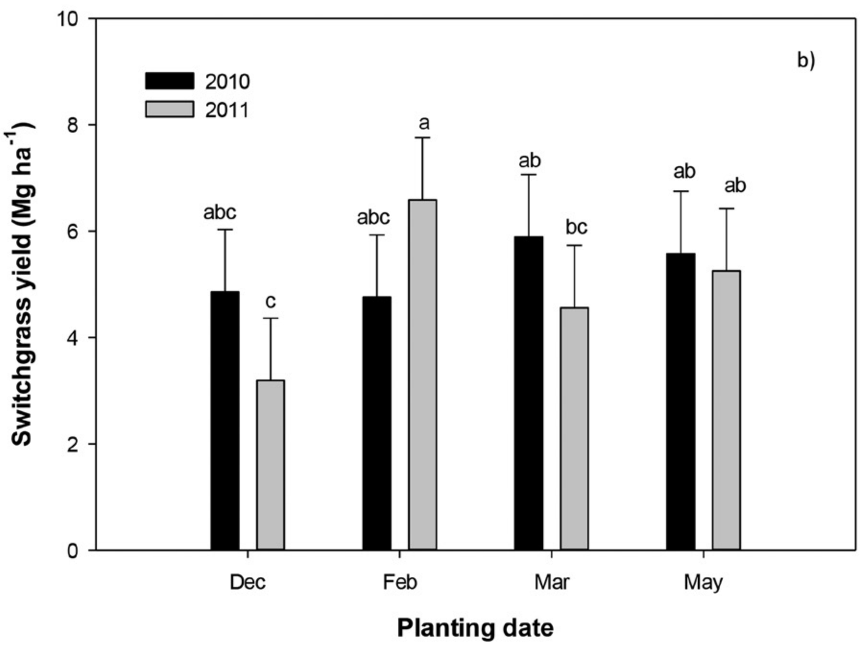


Figure 4. Mean (LS means) switchgrass seedling year (a) plant density and (b) mean (LS means) second year dry matter yield by each of four planting dates (1 December, 1 February, 15 March, and 1 May) during a dormant-season-establishment study conducted at East Tennessee Research and Education Center, Knoxville, TN, 2009 through 2010. Yields were based on dormant-season harvests (15 October–1 November) taken in 2010 from 2008 through 2009 plantings and in 2011 from 2009 through 2010 plantings. Different letters indicate a significant difference ($P \leq 0.05$; LSD = 2.68 and $P \leq 0.05$; LSD = 3.86 for a and b, respectively). Vertical bars are ± one standard deviation.

planting seed with greater dormancy levels than those we tested (>75%) or later planting dates with dormant seed (e.g., after 1 June; Sanderson et al., 1996). In a study conducted in southwest Virginia, high (84%) and low (5%) dormancy switchgrass seed planted in early May showed little difference in second-year yield, but substantial difference in plant population during the seedling year (Sanderson et al., 1996). However, several studies indicate that second-year switchgrass yields may not be particularly sensitive to initial seeding rates (Launchbaugh and Owensby, 1970; Vassey et al., 1985; West and Kincer, 2011). For instance, acceptable stands of switchgrass have been produced from as little as 2.24 kg PLS ha^{-1} in an experimental setting with excellent weed control (Foster et al., 2013). These studies reinforce the fact that typical seeding rates (e.g., 6.7 kg PLS ha^{-1}) provide enough seed (assuming 150,000 seed kg^{-1}, >1,000,000 seed ha^{-1}) to produce the plant population required for a good stand. Clearly, other abiotic and biotic factors, such as fungal infection, endosperm deterioration, seed predators, soil fertility, and

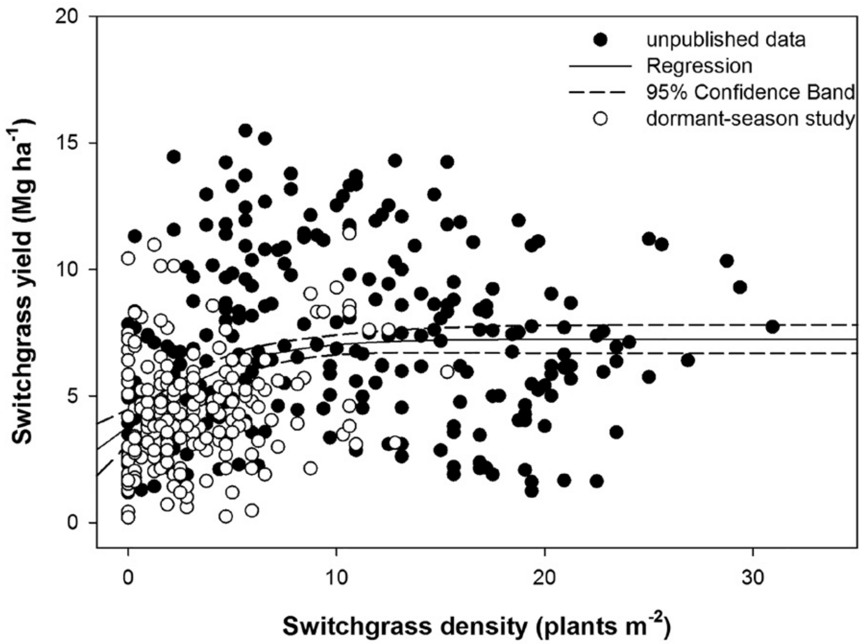


Figure 5. Relationship between switchgrass yield and density (nonlinear regression; equation: Sigmoidal, Sigmoid 3 Parameter) using data from establishment experiments (dormant-season study) at East Tennessee and Highland Rim Research and Education Centers, 2009 through 2011, and unpublished data from additional establishment experiment (unpublished data, 2012) conducted at East Tennessee, Highland Rim, and Milan Research and Education Centers, 2009 through 2011.

plant competition, all may impact seed survival and seedling recruitment (Parrish and Fike, 2005). At the rates we seeded, even with relatively high dormancy rates, we did not see any effect from seeding treatments.

CONCLUSIONS

Although switchgrass has developed dormancy to increase survival in the wild, this trait presents a considerable challenge to its successful use as a forage or biofuel crop. Planting switchgrass during the dormant season may be more reliable for establishing stands than during the growing season, as has been typically recommended. However, yield responses were not different between the two time periods. Even if establishment success is not increased, it is apparent that there is greater flexibility in planting dates with few consistent differences in dates from early December to late May. Furthermore, the decision to plant during the dormant season need not be constrained by seed-dormancy level, at least within the range that was tested in this experiment (45–75%), and seeding rate does not need to be adjusted from growing-season recommendations (6.7 kg PLS ha^{-1}). The variability in establishment success and successive yields, regardless of factors tested in this experiment, underscores the importance of other factors associated with establishment including proper planting technique, and competition control, regardless of time of planting.

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