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# The effect of row spacing and seeding rate on biomass production and plant stand characteristics of non-irrigated photoperiod-sensitive sorghum (*Sorghum bicolor* (L.) Moench)

John L. Snider[a,*], Randy L. Raper[a], Eric B. Schwab[b]

[a] *USDA, Agricultural Research Service, Dale Bumpers Small Farms Research Center, 6883 South State Hwy 23, Booneville, AR, 72927, USA*
[b] *USDA, Natural Resources Conservation Service, 3381 Skyway Drive, Auburn, AL, 36830-6443, USA*

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ABSTRACT

To evaluate row spacing and seeding rate effects on yield and plant stand characteristics of high-biomass sorghum, a photoperiod-sensitive cultivar was sown at three different row spacings (76, 38, and 19 cm) and seeding rates (218,000, 306,000, and 393,000 seeds ha$^{-1}$ for one site-year and 116,000, 204,000, and 291,000 seeds ha$^{-1}$ for three site-years) from 2009 to 2010 in Alabama and Arkansas, USA. Measurements included above-ground dry matter production, plant height, stem density, and stem diameter. Narrower row spacing (i.e. 19 cm) produced the highest biomass for all site-years. Increasing seeding rate did not affect yield for three of the site-years, and decreased yield for one. The 19 cm row spacing produced the highest stem densities. Plant height increased with increasing seeding rates at one site and decreased with higher seeding rates at another site. At one location, stem diameter declined as seeding rates and stem density increased. It was concluded that narrower row spacing (19 cm) provides the maximum yield benefit by significantly increasing stem density, and low seeding rates (116,000 seeds ha$^{-1}$) are preferable because higher seeding rates do not positively affect yield and may cause morphological changes (i.e. taller plants with thinner stems) conducive to lodging.

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## 1. Introduction

The Energy Independence and Security Act of 2007 is intended to lessen U.S. dependence on non-renewable fossil fuel energy sources and requires increased production of alternative fuels to 36 billion gallons by 2022. Because Congress has capped the production of corn-based ethanol production at 15 billion gallons, the remainder of the 36 billion gallons will be comprised of advanced biofuels derived largely from lignocellulosic feedstock sources (Service, 2010). Lignocellulosic bioethanol production has become an attractive alternative to using non-structural carbohydrate (starch and soluble sugars) sources for ethanol production (Sivakumar et al., 2010; Waltz, 2008) because the cellulosic components of plant cell walls represent an abundant feedstock for bioenergy conversion (Sivakumar et al., 2010) and because biofuels can be produced from non-food sources such as corn stover, various grasses, and woody biomass without competing with the production of important food crops (Sivakumar et al., 2010; Waltz, 2008). As a result, a number of crops have been studied for their potential use as dedicated bioenergy feedstock, including grasses such as *Miscanthus* (Fischer et al., 2005), sorghum (Rooney et al., 2007; Venuto and Kindiger, 2008; Wang et al., 2008), and switchgrass (Schmer et al., 2008) and short-rotation woody species such as willow and poplar (Fischer et al., 2005; Aylott et al., 2008; Stolarski et al., 2011).

Sorghum has a number of characteristics making it a promising dedicated biofuel feedstock source, including high productivity (Amaducci et al., 2000; Habyarimana et al., 2004; Rooney et al., 2007), drought tolerance (Amaducci et al., 2000; Rooney et al., 2007), and substantial potential for genetic improvement (Carpita and McCann, 2008; Rooney et al., 2007). Although the amount of starch and soluble carbohydrates produced per unit land area are important for ethanol production from grain and sweet sorghum, respectively, cellulosic ethanol production from high-biomass sorghum requires that the total amount of cellulosic biomass per unit land area be maximized (Rooney et al., 2007; Carpita and McCann, 2008).

A number of studies have evaluated the impact of practical management decisions (i.e. fertilization requirements, row spacing, plant population) on sweet sorghum (Martin and Kelleher, 1984), grain sorghum (Welch et al., 1966; Steiner, 1986), and forage sorghum productivity (Marsalis et al., 2010). Management strategies are well-defined for optimal syrup (Mask and Morris, 1991), grain (Mask et al., 1988), and forage production (Ball, 1998). Recently, Wortmann et al. (2010) showed that bioethanol

* Corresponding author. Tel.: +1 479 675 3834x342; fax: +1 479 675 2940.
*E-mail address:* john.snider@ars.usda.gov (J.L. Snider).

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production from sweet sorghum in Nebraska responded positively to increased N fertilizer application rates (up to 80 kg N $ha^{-1}$) and plant population (up to 175,000 plants $ha^{-1}$) for one of three cultivars evaluated, whereas ethanol yields for the other two cultivars were unaffected by fertilizer application and plant population.

Photoperiod-sensitive sorghum varieties are capable of achieving high levels of biomass production by continuing vegetative growth throughout the season. These varieties do not flower under the day lengths observed during typical southern U.S. growing seasons (Rooney et al., 2007; Venuto and Kindiger, 2008). When compared with sweet and grain sorghum, comparably little information is available on management practices for the production of high-biomass sorghum varieties for bioenergy purposes. For example, Habyarimana et al. (2004) reported that increasing plant densities from 100,000 to 200,000 plants $ha^{-1}$ resulted in higher above-ground yield at only one of three locations in Italy. Venuto and Kindiger (2008) recently reported that a single late-season harvest was superior to two harvests for yield of a number of hybrid forage sorghum and sorghum-sudangrass hybrids (including photoperiod-sensitive genotypes) in central Oklahoma. However, information on the impact of basic agronomic practices such as row spacing and seeding rate on biomass production in photoperiod-sensitive sorghum is limited for the southern U.S. Because photoperiod sensitive sorghum would be harvested for cellulosic biomass rather than for grain, soluble sugars, or as a nutritional source for cattle, row spacing and seeding rates that maximize total above-ground biomass may be different that those utilized for optimal grain, sugar, and forage production. Consequently, the objectives of this research were (1) to measure the effect of row spacing and seeding rate on the yield of a photoperiod-sensitive sorghum cultivar (Sorghum Partners® 1990) and (2) to quantify the effects of row spacing and seeding rate on plant height, stem density, and stem diameter of this cultivar.

## 2. Materials and methods

### 2.1. Study locations and general crop management practices

A total of four site-years were utilized for the current study. In April 2009, plots 3.0 m wide by 9.1 m long were established at E.V. Smith Research Station (EVS 2009), Shorter, AL (85°53′50″W, 32°25′22″N) and at the Gulf Coast Experiment Station (Fairhope 2009), Fairhope, AL (87°52′55″W, 30°32′56″N). The soil in Shorter was a Lynchburg loamy sand (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults) and at Fairhope was a Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults). In April 2010, the experiment was again established at Fairhope, AL (Fairhope 2010) and in June 2010 at the USDA-ARS Dale Bumpers Small Farms Research Center in Booneville, AR (Booneville 2010; 93°59′35″W, 35°5′10″N). The soil in Booneville was a Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudult).

The planting dates for each site-year are as follows: EVS, April 30, 2009; Fairhope, April 8, 2009 and May 5, 2010; Booneville, June 3, 2010. All locations are positioned in the mid-south region of the U.S. and have temperate climates. To more fully characterize each site-year the average maximum temperature ($T_{max}$), minimum temperature ($T_{min}$), and rainfall (mm) are reported in Table 1. Because 7 years of climate data were available for all locations, the 7 year mean for each of the aforementioned climatic variables is also reported for each site-year (Table 1).

A photoperiod-sensitive variety of sorghum (variety 1990) was obtained from Sorghum Partners, Inc. (New Deal, TX) and sown in plots according to the row spacings and seeding rates described in Section 2.2. Variety 1990 is a late maturing, tall silage hybrid (Sorghum Partners, 2009) and produces a head only when there is less than 12 h and 20 min of daylight. Consequently, this variety would be expected to continue vegetative growth through most of the growing season and to produce high biomass yields at all locations utilized in this study.

At planting, 56.0 kg N $ha^{-1}$ was applied and an additional 78.5 kg N $ha^{-1}$ was side dressed later in the spring for a total of 134.5 kg N $ha^{-1}$ on all plots. Soil test recommendations were used for the application of P and K. All other soil fertility and pest control were managed using Auburn University extension recommendations previously developed for forage sorghum. At the Booneville location, an additional 22.4 kg N $ha^{-1}$ was applied at planting due to soil requirements.

### 2.2. Seeding rate and row spacing treatments

Three seeding rates were used for the experiment: low (8.41 kg $ha^{-1}$ for EVS 2009 and 4.48 kg $ha^{-1}$ for all other site-years), medium (11.77 kg $ha^{-1}$ for EVS 2009 and 7.85 kg $ha^{-1}$ for all other site years), and high (15.13 kg $ha^{-1}$ for EVS 2009 and 11.21 kg $ha^{-1}$ for all other site-years) seeding rates. The number of seed per kg were determined, and seeding rates were subsequently expressed as seed $ha^{-1}$ as follows: low (218,000 seeds $ha^{-1}$ for EVS 2009 and 116,000 seeds $ha^{-1}$ for all other site-years), medium (306,000 seeds $ha^{-1}$ for EVS 2009 and 204,000 seeds $ha^{-1}$ for all other site years), and high (393,000 seeds $ha^{-1}$ for EVS 2009 and 291,000 seeds $ha^{-1}$ for all other site-years). Three row spacings were used in the experiment: 76 cm, 38 cm, and 19 cm (drilled), and all plots were directly seeded. Various planting equipment was used at all locations to obtain the multiple row spacings. In 2009 at Auburn and Fairhope, the 19 cm row spacings (drilled) were obtained with a Marliss 3.0 m grain drill (Sukup Manufacturing Company, Sheffield, IA). The wider row spacings of 38 and 76 cm were obtained with a Kinze 6-row planter (Kinze Manufacturing, Inc., Williamsburg, IA) which was set on 76 cm row spacing. To obtain the 38 cm row spacing, the planter was operated a second pass in the previous row middles.

In 2010, a John Deere 1590 10 ft no-till drill (Deere and Co., Moline, IL) was used in Fairhope to obtain all 3 row spacings. Holes in the drill were covered with tape to only allow seeds to come out at the various row spacings. At Booneville in 2010, a Marliss 3.0 m grain drill was again used for the 19 cm row spacing. The wider row spacings were obtained with an experimental AGCO row planter (AGCO Corporation, Duluth, GA) that had individual units that could be turned on or off as needed to obtain both the 38 and 76 cm row spacing. Plant emergence was good across all site-years.

The experimental design for each site-year was a completely randomized design with two independent variables (row spacing

**Table 1**
Average maximum temperature ($T_{max}$), minimum temperature ($T_{min}$), and rainfall during the growing season for four individual site-years and the 7 year mean for each location.

| Site-year | $T_{max}$ | $T_{max}$ (7 year) | $T_{min}$ | $T_{min}$ (7 year) | Rainfall | Rainfall (7 year) |
|---|---|---|---|---|---|---|
| EVS 2009 | 28.7 °C | 29.3 °C | 19.2 °C | 18.8 °C | 805 mm | 598 mm |
| Fairhope 2009 | 30.4 °C | 30.0 °C | 21.0 °C | 20.0 °C | 799 mm | 691 mm |
| Fairhope 2010 | 31.9 °C | 31.0 °C | 22.5 °C | 21.0 °C | 693 mm | 686 mm |
| Booneville 2010 | 33.0 °C | 31.2 °C | 17.5 °C | 16.3 °C | 324 mm | 487 mm |