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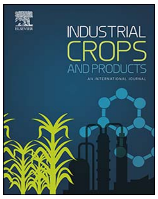

Performance evaluation of biomass sorghum in Hawaii and Texas

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ABSTRACT

Although biomass sorghum [*Sorghum bicolor* (L.) Moench] has been identified as a high yielding bioenergy feedstock crop on the continental USA, there is however lack of conclusive data on its performance in Hawaii (HI). The objectives of this study were to (i) determine the adaptability and productivity of two biomass sorghum hybrids, and (ii) identify the associated crop parameter attributes and environmental factors for high biomass yields. Two comparative trials were conducted, one on Maui island, HI and the other at Temple, Texas (TX). At Temple, the biomass sorghum hybrids responded as expected, growing to heights in excess of 3 m and producing average biomass yields of 37.4 Mg ha^{-1}. The high leaf area indices (LAI, 7.8–9.8) intercepted over 90% incident photosynthetically active radiation (PAR) at LAI $>$ 4, while the computed average light extinction coefficient (*k*) was 0.48. An average plant growth rate (PGR) of 189 kg dry biomass ha^{-1} day^{-1} was achieved, while the average radiation use efficiency (RUE) was 2.75 g MJ^{-1}. In sharp contrast to the results obtained at Temple, the two sorghum hybrids planted on Maui behaved like photoperiod insensitive short day grain sorghums; lower plant heights ($<$ 2.0 m), LAI (average, 3.8) and PGR prior to heading (average, 41 kg ha^{-1} day^{-1}), flowered early (~90 days after planting), and had aboveground biomass yields reduced by 76%. The study underscored the importance of not only choosing the right bioenergy crop species, but also the suitability of target environments, planting date and management practices. The crop parameters determined at Temple can be incorporated into crop and environmental simulation models such as ALMANAC, EPIC/APEX and SWAT to model various biomass sorghum cropping systems and their associated environmental impacts.

1. Introduction

The state of Hawaii (HI) depends on imported coal and oil for 95% of its energy (US DOE, 2015). Unsurprisingly, its residents pay among the highest prices in the USA for gasoline, residential fuel gas, and electricity (Hawaii State Energy Office, 2015). Faced with this energy challenge, HI has aggressively sought alternative and renewable energy resources to reduce this overdependence on imported energy.

Several US federal and private sector funded projects and demonstrations have been conducted to identify appropriate processes and feedstocks that are economically feasible for producing biofuel in Hawaii (Kinoshita and Zhou, 1999). Although sugarcane (*Saccharum officinarum* L.) is viewed as the ideal sugar-to-ethanol biofuel, its production in HI has declined significantly since the 1970s. This decline is due to a number of factors that include low prices (due to the phasing out of the USA government's protections that limited foreign imports), competition from artificial sweeteners, and low cost production from such countries as Mexico, Brazil, India, and China (Gaddis, 2013; Meki et al., 2015).The total area under sugarcane today is now less than 16,200 ha from a high of 103,275 ha in the 1930s. The large tracts of fallow agricultural lands which used to be under sugarcane production are now transitioning into diversified crops. Other land has been converted to urban developments but still large tracts of prime land now lie fallow or are under pasture (Kinoshita and Zhou, 1999).

Abbreviations: DAP, days after planting; FIPAR, fraction of intercepted photosynthetically active radiation; HC & S, Hawaii Commercial & Sugar Company; k, light extinction coefficient; LAI, leaf area index; PAR, photosynthetically active radiation; PGR, plant growth rate; RUE, radiation use efficiency

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In HI sugarcane competes with other sectors of the economy for the scarce water resources, and hence the interest in alternatives that optimize water use efficiency. Among the identified potential cellulosic feedstocks, based on their high biomass yields, adaptability to HI conditions, and are relatively drought tolerant, are Napier grass (*Pennisetum purpureum*) (Kinoshita and Stackmann, 1994) and energycane (*Saccharum* hyb.) (Alexander, 1985).

Biomass sorghum hybrids have been demonstrated on the continental USA to produce high biomass yields in as few as 90–100 days, and in addition, are relatively drought tolerant (Rooney et al., 2007; Venuto and Kindiger, 2008; Blade Energy Crops, 2010). To our knowledge only one study (Smith et al., 1987) has evaluated the production potential of sweet sorghum as a renewable biofuel resource for HI. The results of Smith et al. (1987) demonstrated that sweet sorghum is far more widely adapted than was anticipated for a plant of tropical origin and certainly has good potential as a biofuel feedstock in HI. While sweet sorghum has high yields of both fiber and fermentable sugars (15–23%) (Sarath et al., 2008; El Bassam, 2010) biomass sorghums have been bred to specifically maximize cellulosic content (at least 75% cellulosic content) (EPA, 2015). This study was prompted by the lack of conclusive data on the performance of biomass sorghums [*Sorghum bicolor* (L.) Moench] in HI and is a component of a bioenergy project whose overall objective was to evaluate the feasibility and sustainability of producing select bioenergy feedstocks in HI (Meki and Kiniry, 2013; Meki et al., 2015).

The hypothesis being addressed in this paper is that although there is great interest in growing biomass sorghums as a bioenergy feedstock in HI, there is still limited scientific information on how they perform under different environmental and management practices. To this end, we conducted a field study at the Hawaii Commercial & Sugar Company (HC & S) sugarcane plantation, on the Island of Maui, HI, in collaboration with researchers from the University of Hawaii at Manoa to (i) determine the adaptability and productivity of two biomass sorghum hybrids grown as potential biofuel feedstock crops, and make performance comparisons with a similar trial conducted at Temple, TX, a region known to be well adapted for maximum production of biomass sorghums, and (ii) identify the crop parameters and environmental factors that contribute to the high biomass yields.

2. Materials and methods

2.1. Plant material

Two Wilbur-Ellis Co.[1] high biomass sorghum hybrids Integra 405 (I-405) and Integra 1990 (I-1990)[2] were selected for both field experiments conducted at HC & S, Maui, HI and Temple, TX. When grown at continental USA sites the two hybrids were recognized to have the following characteristics; high biomass yields, drought tolerance, (but are also highly recommended for irrigated production), very tall plants (3.0–3.6 + m) with resistance to lodging, early vigor, high forage quality with a low lignin content. Integra-405 has high sugar content (sweet juicy stalks), while I-1990 is of average sugar content. Integra 405 is a late maturing hybrid while I-1990 is photoperiod-sensitive. Photoperiod sensitive sorghums will not flower when grown when the daylength is more than the photoperiod trigger of 12 h 20 min, and hence produce high biomass through continued vegetative growth.

2.2. Study sites and cultural practices

Field studies were conducted at the HC & S plantation (lat. 20.89°N, long. −156.41°W; mean elevation ~100 m asl) and at the USDA ARS, Grassland, Soil and Water Research Laboratory, Temple, TX (lat. 31.09°N, long. −97.36°W; elevation ~219 m asl) during the 2012 and 2013 growing seasons. At HC & S, field trials were established on two fields: field (F) 410 which is a high elevation site (~300 m asl) and is on a Aridisol (Keahua series), which is a fine, kaolinitic, isohyperthermic Ustic Haplocambid; F718 is a low elevation site (~30 m asl) and is on a Mollisol (Ewa series), which is a fine, kaolinitic, isohyperthermic Aridic Haplustolls (USDA NRCS, 2011). Two elevations were chosen due to previous observations which indicated that although certain bioenergy species such as Napier grass are well adapted and yield well at most elevations, sugarcane and energycane are not well adapted to higher elevations and their yields are much lower (Mae Nakahata and Richard Ogoshi, co-authors, pers. comm.). So the two elevations were chosen so as to assess the performance of the two biomass sorghum hybrids at the two elevations. At Temple, the field trials were conducted on a Vertisol (Houston black clay), which is a fine, smectitic, thermic Udic Haplusterts (USDA NRCS, 2011). A few selected key soil properties of the three soils are presented in Table 1. At HC & S and Temple, weather data for the study fields was respectively obtained from an on-field and on-station weather station.

At Temple, a completely randomized repeated measures design with three replicates was used. Overall plot sizes were approximately 12 m by 12 m to allow for unbiased repeated biomass samplings throughout the growing season. Roundup (*N*-(phosphonomethyl)glycine, $C_3H_8NO_5P$) herbicide was applied at a rate of 3.51 L/ha to control weeds a week prior to planting. The field was conventionally tilled (plowing followed by disking) and fertilized with 120 and 30 kg ha^{-1} of N and P fertilizers, respectively. Fertilization rates were based on data reported in the literature (Blade Energy Crops, 2010; Maughan et al., 2012; Rocatelli et al., 2012; Snider et al., 2011; Undersander et al., 1990). The 2012 and 2013 field plots were established on 19 and 8 April, and final harvests were on 20 and 3 September, respectively. The biomass sorghums were seeded at the recommended seeding rates of 180,000 seeds ha^{-1} (Blade Energy Crops, 2010) using the Great Plains 1510 minimum till grain drill (Great Plains Manufacturing, Salina, KS). To ensure near-optimum growing conditions throughout the growing season, limited supplementary irrigation water of 200 mm and 150 mm was applied in 2012 and 2013, respectively.

At HC & S, the sorghum hybrids were planted in a field previously under sugarcane. A group-balanced block experimental design which included three other candidate bioenergy crops: sugarcane, energycane and Napier grass was used. Fields were subsoiled with a deep ripper (60 cm depth), followed by disc harrowing (45 cm). Trial plots were established on September 9, 2011, with final harvests on September 11, 2012 (F410) and September 12, 2012 (F718). Experimental plots in both Temple and at HC & S were replicated three times. At HC & S individual plots (15 m × 11 m) consisted of four rows of grass, centered on a drip irrigation line, the distances between rows and drip lines were 0.23 m and 2.7 m as described in Meki et al. (2015). This design was used to accommodate the sugarcane infrastructure of drip lines already in place. A pre-emergence herbicide mix containing atrazine (1-chloro-3-ethylamino-5-isopropylamino-2, 4, 6-triazine), 2, 4-D (2, 4-dichlorophenoxyacetic acid), Prowl ((*N*-1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine), Rifle (3, 6-dichloro-2-methoxybenzoic acid), and Velpar (3-cyclohexyl-6-dimethylamino-1-methyl-1, 3, 5-triazine-2, 4(1H,3H)-dione) was applied to control weeds. Seeds were hand sowed into the rows at a target seeding rate of 143,000 plants ha^{-1}. Although the hand sowed seeding rate at HC & S was lower than that at Temple, sorghums have the ability to compensate (or self-thin) the plant population through tillering (Snider et al., 2011; Gerik and Neely, 1987), especially under drip and fertigated field conditions. Annual rainfall varied from 250 to 1500 mm in the irrigated plots (92% of total cultivated area). Plants were drip-irrigated weekly as needed to prevent any water stress. The amount of water applied was determined by the plantation's crop production managers who controlled the whole

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[1] http://ag.wilburellis.com/Products/Pages/Home.aspx (Accessed 17 May 2016).

[2] Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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