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Source: Florida Entomologist, 96(2) : 512-528

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.096.0217

ENTOMOLOGIC AND AGRONOMIC EVALUATIONS OF 18 SWEET SORGHUM CULTIVARS FOR BIOFUEL IN FLORIDA

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Abstract

Sweet sorghum [(*Sorghum bicolor* L. Moench); Cyperales: Poaceae] is a summer annual crop suitable for use as a biofuel feedstock. The juice from harvested sweet sorghum stalks can be readily converted into ethanol. The purpose of this study was to identify potential arthropod pests of promising sweet sorghum cultivars grown for biofuel on Histosols (muck soil) in southern Florida. This field study was conducted at the Everglades Research and Education Center at Belle Glade, Florida in 2010. Eighteen sweet sorghum cultivars planted at 3 dates were evaluated for insect feeding. Foliar damage was measured during the whorl stage and boring within stalks was measured at harvest. Seedling damage caused by *Elasmopalpus lignosellus* Zeller (Lepidoptera: Pyralidae) and black cutworm *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) reduced the stand of most of the cultivars tested. Foliar feeding by *Spodoptera frugiperda* L. (Lepidoptera: Noctuidae) larvae was significantly affected by cultivar and planting date. Whorl infestations above 90% were observed for all cultivars at 30- and 55-d after the early May and June planting dates. Percentage of stalks bored by sugarcane borer *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) larvae varied significantly among cultivars and planting dates reaching 13.7% in cv 'Sugar T' planted in early May. Twelve species of stinkbugs (Heteroptera: Pentatomidae) and one leaf-footed bug [*Leptoglossus phyllopus* (L.) (Heteroptera: Coreidae)] fed extensively on developing seeds during the milk and soft dough stages. Days to harvest was cultivar dependent and ranged from 84 to 153 d. Fresh and dry weights, percentage juice extraction, brix value and potential ethanol yield varied significantly among cultivars and planting dates. Significantly lower yields were found for all cultivars when planted in Jun compared to late Mar and May.

Key Words: fall armyworm, lesser cornstalk borer, sugarcane borer, juice extraction, ethanol

Resumen

El sorgo dulce [(*Sorghum bicolor* L. Moench); Cyperales: Poaceae] es un cultivo anual de verano adecuado para su uso como materia prima para biocombustibles. El jugo de los tallos cosechados de sorgo dulce puede ser fácilmente convertido en etanol. El propósito de este estudio fue identificar las plagas potenciales de artrópodos de cultivares promisorios de sorgo dulce cultivados para biocombustibles en Histosoles (suelo escombrero) en el sur de la Florida. Se realizó un estudio de campo en el Centro de Investigación y Educación de los Everglades en Belle Glade, Florida en el 2010. Dieciocho variedades de sorgo dulce sembrados en 3 fechas fueron evaluados para la alimentación de insectos. Se midió el daño foliar durante la etapa de cogollo y el barrenamiento dentro de los tallos en el tiempo de cosecha. Daño de las plántulas causado por *Elasmopalpus lignosellus* Zeller (Lepidoptera: Pyralidae) y el gusano cortador negro *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) redujo la cantidad del cultivo en la mayoria de los cultivares probados. La alimentación foliar hecha por larvas de *Spodoptera frugiperda* L. (Lepidoptera: Noctuidae) fue significativamente afectada por la clase de cultivar y la fecha de siembra. Se observaron infestaciones de los cogollos de mas del 90% en todos los cultivares entre los 30 - y 55-dias després de la fecha de siembra al principio de mayo y de junio. El porcentaje de tallos barrenados por larvas del barrenador de la caña de azúcar *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) varió significativamente entre los cultivares y fechas de siembra alcanzando el 13.7% en el cultivar 'Sugar T' sembrado al principio de mayo. Doce especies de chinches hediondas (Heteroptera: Pentatomidae) y una chinche de patas de hojas [*Leptoglossus phyllopus* (L.) (Heteroptera: Coreidae)] se alimentaron extensamente sobre las semillas desarrolladas durante las etapa de leche y de masa blanda del cultivo. El numero de días hasta la cosecha fue dependiente del cultivar y varió de 84 a 153 dias. El peso fresco y el peso seco, el porcentaje de jugo extraido, el valor brix y el rendimiento potencial de etanol varió significativamente entre los cultivares y fechas de siembra. Se encontraron rendimientos significativamente más bajos en todos los cultivares sembrados en junio en comparación con los sembrados al final de marzo y de mayo.

Palabras Clave: gusano cogollero, barrenador menor del tallo de maíz, barrenador de la caña, extracción de jugo, etanol

Sweet sorghum, *Sorghum bicolor* (L.) Moench; Cyperales: Poaceae, is an annual grass that can be ratooned to produce multiple crops in Florida. It can be grown under hot and dry climatic conditions for syrup, forage, and silage (Kresovich 1981; Almodares & Hadi 2009) and as a supplementary sugar crop (Kualarni et al. 1996). Sugarcane is a major crop in southern Florida produced on 160,660 ha in 2011 (USDA 2012). Similar to sugarcane, the juice from harvested sweet sorghum stalks can be converted into ethanol using currently available, conventional fermentation technology (Smith et al. 1987). Compared to sugarcane, sweet sorghum has advantages of shorter growing period, greater water-use efficiency and wider adaptability (Reddy et al. 2005). The short growth cycle allows 2 or 3 sweet sorghum harvests per year in areas with a sufficiently long growing season (Almodares & Hadi 2009), such as southern Florida. Sweet sorghum would also be harvested and processed during the off-season of sugarcane, potentially allowing for extended use of currently available equipment and infrastructure.

Sweet sorghum yield can be affected by planting date, environment, and cultivar. In Mississippi, yields of 'Rio' sweet sorghum were lower when planted in June as compared to Apr and May (Broadhead 1969). In California, cultivars matured faster and yielded more at Davis, California than in Salinas, California (Hills et al. 1990); however, percent sucrose was greater in Salinas making up for some of the fermentable yield loss. In Florida, fresh weights of 'Dale', 'M-81E' and 'Topper 76-6' ranged from 65 Mg ha^{-1} to 86 Mg ha^{-1} across 3 locations when planted in Apr (Erickson et al. 2011). At 9 locations across the southeastern U.S., mean stripped stalk yields ranged from 32.5 Mg ha^{-1} to 59.3 Mg ha^{-1} for cv 'Theis' and 32.7 Mg ha^{-1} to 55.6 Mg ha^{-1} for cv 'Brandes' (Broadhead et al. 1974).

Insect feeding on sweet sorghum has been documented by several workers over the last 30 years (Brewbaker 1975; Duncan & Gardner 1984; Fuller et al. 1988; Youm et al. 1990; Rebe et al. 2004), but prior to the research described below begun in 2010 the most recent work in Florida had been conducted by Anderson & Cherry (1983). Following the suggestion by Cartwright (2008) that increased biofuel production may result in the need for increased pest control in such crops, we conducted field trials at 3 planting dates to identify potential arthropod pests on 18 sweet sorghum cultivars with promising yields for southern Florida.

Materials and Methods

Agronomic Procedures

The trial was conducted at the University of Florida Everglades Research and Education Center (EREC) at Belle Glade, Florida in 2010. The soil at the planting site was a Lauderhill Muck (Euic, hyperthermic Lithic Haplosaprists). The field had been previously planted to sugarcane and had been amended with mill mud (by product of sugarcane milling consisting primarily of ground sugarcane leaves and stalk material, soil, and lime added in the sugar clarification process) 5 yr prior to this trial. Eighteen sweet sorghum cultivars were evaluated at each of 3 planting dates: 31 Mar, 4 May and 10 Jun. 'Della', 'Keller', 'Simon' and 'Sugar Drip' seed were purchased directly from the University of Kentucky (Lexington, Kentucky, USA). 'Sile All II' and 'Sugar T' were obtained from Advanta (Hereford, Texas, USA). 'Dale', 'M81-E', 'Theis' and 'Top 76-6' seeds were purchased directly from MAFES Foundation Seed (Mississippi State University, Mississippi, USA). Colloquially referred to as 'Topper 76-6' and 'Topper', the official release name Top 76-6 (Day et al. 1995) will be used throughout this report. 'Brandes', PI-152733 ['Merissa (Bari)'], PI-154844 ('Grassl'), PI-156463 ('Dobbs'), PI-157033 ('Ifube #18'), PI-247744 ('U.G. 6.7') and PI-257603 ('#9 Gambela') seed came from open pollinated seed increases of original seed lots obtained from the USDA ARS National Plan Germplasm System (GRIN) (USDA ARS 2012) grown at EREC between Apr and Aug 2009. 'Brandes BG' was the designation of seed obtained from a selection of Brandes that grew at EREC with uniform growth and maturity during 2009 trials.

The cultivars were planted in a randomized complete block design with 4 replications at each planting date. Three rows 7.62 m long of each cultivar were planted adjacent to each other in each replication (3 rows × 18 cultivars for a total 54 rows). Replicates within planting dates were separated by 4 m unplanted soil. To simplify hand planting, seed furrows approximately 5 cm deep on 0.76 m spacing were made using a John Deere Max Merge 7000 planter (John Deere Corp. Moline, Illinois, USA) that also dispensed starter fertilizer (N-P-K: 10-37-0) into the seed furrows at 395 kg ha^{-1}. Seeds were hand planted 7 to 9 cm apart in the furrows, covered with soil using hoes and the soil compressed over the seed by walking several times over the seed rows. All agrichemicals used in the trial are currently labeled for use in grain sorghum. Atrazine (2.2 kg ha^{-1}) was applied pre-emergence for weed control the day following each planting. Chlorpyrifos (1.1 kg ha^{-1}) was applied in a tank mix with the atrazine in the last 2 plantings to reduce stand loss observed in the first planting caused by lesser cornstalk borer *Elasmopalpus lignosellus* Zeller (Lepidoptera: Pyralidae) and black cutworm *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae). No foliar insecticide or fungicide treatments were applied to any of the cultivars in any of the plantings. In the last 2 plantings, a tank mix of atrazine and pendimethalin (both at 0.5 kg ha^{-1}) was applied to all cultivar plots for weed control when the sorghum plants were 30 cm tall and had been hilled. Thirty days after planting, 5.5 kg ha^{-1} of 20-20-20 (N-P-K) and 5.5 kg ha^{-1} of manganese sulfate were applied as foliar fertilizer to all cultivar plots.

Insect Studies

Plants were examined weekly for symptoms of insect feeding. The soil around seedlings showing plant stress symptoms from root pruning, hypocotyl or subsurface stems was carefully excavated to locate insects associated with such damage. Insects were hand collected and taken to a laboratory. Immature stages of Lepidoptera were held in plastic bags with sorghum seedlings at 27 °C until the adult stage to aid species identification. Feeding damage by fall armyworm larvae *Spodoptera frugiperda* L. (Lepidoptera: Noctuidae) was evaluated 55-d post planting in each planting. Excessive early feeding damage was noted across cultivars in the second and third plantings; therefore, fall armyworm damage was also evaluated at 30-d post planting in these later plantings. Ten plants were randomly selected in the center row of each cultivar in each replicate for rating using the visual foliage damage scale for fall armyworm developed by Davis et al. (1992). Seed heads were sampled 1 to 2 d prior to stalk harvest for Hemiptera, Homoptera, and Lepidoptera by quickly bagging (3.74 L plastic bag) and then severing 5 individual seed heads from the center row of each cultivar in each replicate. The seed heads were returned to the laboratory and stored in a freezer until the captured insects could be counted and identified to species with the aid of a dissecting microscope. Stalks from all 3 plant crops and ratoon crops of the first and second plantings were examined for stem borers. Thirty stalks of each cultivar in each replicate were cut at 7 to 8 cm above the soil surface, bundled and returned to the laboratory where the stalks were quartered lengthwise and examined for galleries and sugarcane borer larvae *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae). The number of internodes and bored internodes were counted on each stalk.

Harvest and Yield Measurements

Only the plant crops (produced directly from seed) of each planting were harvested for yield measurements, because the randomized plot design for cultivars within a replicate, and up to 60 d variation in maturation rates among cultivars, resulted in great variation in light exposure of the ratoon crops (produced from stubble of plant crop) within and among cultivars. Sugar concentration in sweet sorghum stalks generally increases from the milk to soft dough stage of the seed and then declines as the seeds become more mature (Hills et al. 1990). Therefore, cultivars were harvested at the soft dough stage to maximize sugar yield. Seed heads were monitored twice each week beginning 3 wk after initial anthesis. All 4 replicates of a cultivar within a planting date were harvested on the same date when > 85% of the seed heads had reached at least soft dough stage, but before 10% of the heads had reached hard dough stage. All stalks within a 4-meter section in the center row of each plot were harvested by cutting at 10 to 15 cm above the soil surface. Stalk number and fresh weight were recorded with intact seed heads in the field. Fifteen stalks were sub-sampled at random from the original 4-meter-row sample and weighed with and without seed heads for use in calculating fresh weight (Mg ha^{-1}) without seed heads. Fresh weight was reported herein, because it is used in the calculation of sugar yield and percentage juice, and is an important consideration for calculating costs for transporting the harvested sweet sorghum crop to processing mills. Dry weight is also reported for those interested in cellulosic ethanol production or gasification of dry matter for industrial purposes. The 15-stalk samples were each chopped using a modular sugarcane disintegrator (model 132S, Codistil S/A Denini, Piracicaba, São Paulo, Brazil) within 2 h of harvest in preparation for laboratory measurement of parameters used for estimating sugar and ethanol yield. Two sub-samples were collected from each chopped sample. A 900 to 1000 g fresh weight sub-sample was first collected to measure juice extraction and brix. Subsamples were placed in a hydraulic press (model D-2500-II, Codistil S/A Dedini, Piracicaba, São Paulo, Brazil) for 30 s at 211 kg cm^{-2}. Weight and volume of the extracted juice were recorded for use in calculating percentage juice extraction and sugar yield. Brix, a measure of the mass ratio of soluble solids to water, is a widely used approximation for sugar concentration in stalks (Teetor et al. 2011). Brix concentration (total soluble solids g kg^{-1}) of the extracted juice was determined using a refractometer (model RFM 91, Bellingham and Stanley Inc., Turnbridge Wells, Kent, United Kingdom). Percentage dry matter (Mg ha^{-1}) was calculated from a second subsample of 1500 to 2000 g fresh weight dried at 48 °C to constant weight in a walk-in drying room (Vollrath, Refrigeration Division, River Falls, Wisconsin, USA).

In estimating sugar yields and potential ethanol yields, we assumed that 75% of brix were fermentable sugars (Teetor et al. 2011) and the brix of the theoretical juice was equivalent to the brix values we measured on our actual expressed juice samples. Sugar yield (Mg ha^{-1}) was calculated using the formula: FW × %JE x Brix × 0.75; where FW = fresh weight (Mg ha^{-1}) of 4-m samples and % JE = percentage juice extraction. Potential ethanol yield (liter ha^{-1}) was calculated based on the assumptions that 1.49 kg of sugar could produce 1 liter of ethanol and a 95% sugar-to-ethanol conversion efficiency (Smith et al. 1987).

Data Analyses

Percentage whorl infestation was calculated at the 55-d sample only using the number of whorls infested with fall armyworm from these same plants. Less than 0.1% of stalks in the plant crops were infested with stem borers, and the ratoon crop of the third planting was not sampled due to excessive lodging, broken stalks and freeze damage. Therefore, percentage bored stalks and internodes were calculated for each cultivar in the ratoon crops of the first and second plantings only. Variability in stink bug counts was too great among heads to examine potential differences among cultivars. Therefore, proportions of the total stink bug and leaf footed bug population were calculated by species for each harvest date. The effects of cultivar, planting date and their interaction on fall armyworm leaf damage, percentage sugarcane borer infestation, and 6 yield parameters were tested using analysis of variance (Proc GLM, SAS Institute 2008). Planting date, cultivar and their interaction term were used as sources of variation in the model. Mean separation tests were conducted using Least Significant Difference (LSD) tests where ANOVA indicated that model parameters were significant sources of variation.

Results

Insect Infestation

Germinating seeds and seedlings were the target of wireworms and Lepidoptera larvae, particularly in the first planting that was not treated at planting with chlorpyrifos. Up to 10% of seedlings in plots were killed by the wireworm *Melanotus communis* (Gyllenhall) (Coleoptera: Elateridae). Other wireworms found associated with damaged sweet sorghum seedlings were *Conoderus* spp. and *Glyphonyx bimarginatus* Schaeffer. Lesser cornstalk borer *Elasmopalpus lignoselus* (Zeller) (Lepidoptera: Pyralidae) was the most destructive of the seedling insect pests in our trial, reducing stand by up to 50% in some plots within several weeks of planting. Black cutworm larvae *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) were found feeding on seedlings in the first planting. While less than 5% of seedlings were damaged by cutworm larvae in current study, stand loss by black cutworms was nearly complete in a nearby EREC field of M-81E sweet sorghum planted in late Mar 2010 following back to back crops of sweet corn *Zea mays* L.

Fall armyworm was the most significant foliar feeder encountered during the trial. These larvae began feeding on the seedlings soon after they emerged and continued throughout the vegetative growth cycle until the boot began to emerge from the whorl. The range of percentage whorl infestation at 55 d was wider in the first planting (35 to 77%) than in the second (92 to 100%) and third (97 to 100%) plantings (Table 1). No apparent resistance to feeding was observed during the study. Cultivars with whorl infestations < 50% in the first planting (Dale, Della, Sugar Drip, Keller, Sugar T, Brandes BG and Theis) were all 100% infested in the second and third plantings. Fall armyworm caused various amounts of damage up to and including excessive whorl damage leading to the death of the growing point of sweet sorghum plants. Minor damage also was caused by *Marasmia trapezalis* (Guenee) (Lepidoptera: Pyralidae) through tying together tips of the emerging whorl leaves and feeding within the whorl. The authors have observed the cryptic green colored larvae of this species causing the same type of damage to maize and sugarcane throughout southern and central Florida. Corn leaf aphids *Rhopalosiphum maidis* Fitch and bird cherry oat aphids *R. padi* (L.) (Homoptera: Aphididae) were observed in < 1% of the whorls in all 3 plantings, but no damage was observed in any of the cultivars as a result of their feeding. Greenbug *Schizaphis graminum* (Rondani) (Homoptera: Aphididae) were not observed on any of the cultivars on any of the plantings. Nymphs of the two-lined spittlebug *Prosapia bicincta* (Say) (Homoptera: Cercopidae) were found feeding within spittle masses on the brace roots and stalks beneath the brace roots on < 0.1% of the stalks. An unidentified species of rust mite (Actinedida: Eriophyidae) was found most commonly on M-81E where it produced rusty red colored spots between the veins visible as a brownish discoloration on the upper sides of the leaves in the mid to upper canopy during the late summer and early fall months.

TABLE 1. MEANS[1] ± SEM OF FALL ARMYWORM WHORL INFESTATION AND LEAF DAMAGE RATINGS[2] AT 30- AND 55-D POST PLANTING BY SWEET SORGHUM CULTIVAR.

	31 Mar planting		4 May planting			10 Jun planting		
	55-d sample		30-d sample	55-d sample		30-d sample	55-d sample	
Cultivar	% I	DR	DR	% I	DR	DR	% I	DR
'Dale'	35.0	1.3 ± 0.3 c-f	5.9 ± 0.4 b-g	100	6.2 ± 0.3 bcd	6.6 ± 0.2 b-e	100	3.7 ± 0.2 g
'Della'	40.0	1.0 ± 0.2 ef	5.4 ± 0.4 e-h	95.0	4.7 ± 0.3 i	5.5 ± 0.3 h	97.5	3.6 ± 0.3 g
'Simon'	67.5	2.1 ± 0.3 ab	6.0 ± 0.4 a-f	100	4.9 ± 0.2 ghi	6.6 ± 0.2 bcd	100	3.7 ± 0.2 g
'Sugar Drip'	47.5	1.6 ± 0.3 b-f	6.3 ± 0.3 a-e	97.5	4.7 ± 0.3 hi	6.0 ± 0.3 d-h	100	4.1 ± 0.2 efg
'Keller'	42.5	1.1 ± 0.3 d-f	5.6 ± 0.3 c-h	97.5	5.0 ± 0.3 f-i	5.8 ± 0.3 e-h	100	4.2 ± 0.2 efg
'Sile All II'	67.5	2.3 ± 0.3 ab	5.0 ± 0.4 gh	100	6.4 ± 0.3 bc	6.7 ± 0.3 bcd	100	4.4 ± 0.2 c-f
'Sugar T'	47.5	1.6 ± 0.3 b-f	6.3 ± 0.3 a-e	97.5	5.5 ± 0.3 d-g	5.7 ± 0.3 gh	100	4.0 ± 0.2 fg
'Brandes BG'	45.0	1.7 ± 0.3 a-e	7.0 ± 0.3 a	97.5	5.6 ± 0.3 d-g	6.2 ± 0.3 c-g	100	5.0 ± 0.3 abc
'#9 Gambela'	65.0	2.1 ± 0.3 ab	6.5 ± 0.4 abc	97.5	7.2 ± 0.3 a	7.8 ± 0.2 a	100	5.1 ± 0.2 ab
'Theis'	35.0	0.9 ± 0.2 f	6.7 ± 0.3 ab	100	6.0 ± 0.2 b-e	5.8 ± 0.3 fgh	100	3.7 ± 0.2 g
'Brandes'	77.5	2.3 ± 0.4 ab	6.2 ± 0.3 a-e	100	6.2 ± 0.2 b-e	5.7 ± 0.3 fgh	100	5.2 ± 0.3 a
'M81-E'	52.5	1.6 ± 0.3 b-f	6.2 ± 0.3 a-e	100	6.4 ± 0.2 bc	6.4 ± 0.3 c-f	100	4.1 ± 0.2 efg
'Top 76-6'	57.5	1.9 ± 0.3 a-d	5.8 ± 0.3 b-g	100	5.9 ± 0.2 b-e	6.5 ± 0.3 cde	100	4.5 ± 0.2 b-f
'Grassl'	55.0	2.0 ± 0.3 abc	5.2 ± 0.3 fgh	100	6.5 ± 0.2 ab	7.3 ± 0.2 ab	100	4.6 ± 0.2 a-f
'U.G. 6.7'	42.5	1.2 ± 0.3 c-f	5.5 ± 0.4 d-h	100	5.9 ± 0.3 b-e	6.8 ± 0.2 bc	100	4.9 ± 0.2 a-d
'Merissa (Bari)'	57.5	2.0 ± 0.3 abc	6.5 ± 0.4 a-d	100	5.9 ± 0.3 b-e	7.0 ± 0.2 bc	100	4.5 ± 0.2 b-f
'Dobbs'	67.5	2.2 ± 0.3 ab	6.4 ± 0.4 a-d	92.5	5.7 ± 0.3 c-f	5.6 ± 0.4 gh	100	4.6 ± 0.3 a-e
'Ifube #18'	65.0	2.6 ± 0.4 a	4.7 ± 0.4 h	97.5	6.1 ± 0.3 b-e	6.6 ± 0.3 bcd	100	4.3 ± 0.2 def
$F; p > F$[3]		2.81; < 0.0001	3.10; < 0.0001		6.70; < 0.0001	5.41; < 0.0001		5.40; < 0.0001

[1]Means in a column followed by the same letter are not significantly different (LSD, $p = 0.05$).
[2]% I = percentage whorl infestation by fall armyworm; DR = fall armyworm leaf feeding damage rating: 0 to 9 scale (Davis et al. 1992).
[3]Analysis of variance for cultivar effects by planting date, df = 17, 702 (Proc GLM, SAS 2011).

Fall armyworm damage ratings at 55-d after planting varied significantly by planting date ($F = 1131.64$; df = 2, 2106; $P < 0.0001$), cultivar ($F = 9.01$; df = 17, 2106; $P < 0.0001$) and their interaction ($F = 2.57$; df = 34, 2106; $P < 0.0001$). Mean ± SEM damage ratings across cultivars at 55 d after planting were the lowest in the first planting (1.73 ± 0.07), significantly greater in the third planting (4.33 ± 0.05) and greatest in the second planting (5.81 ± 0.07). Damage ratings at 30-d also varied significantly by planting date ($F = 15.39$; df = 1, 1404; $P < 0.0001$), cultivar ($F = 3.19$; df = 17, 1404; $P < 0.0001$) and their interaction ($F = 4.77$; df = 17, 1404; $P < 0.0001$). Mean ± SEM damage ratings across cultivars at 30-d after planting were significantly lower in the second planting (5.94 ± 0.08) than in the third planting (6.35 ± 0.07). Therefore, the data were separated by planting date and re-analyzed for cultivar effects. Mean fall armyworm damage ratings at 55-d ranged from 0.85 for Theis to 2.55 for Ifube #18 in the first planting (Table 1). Ratings for fall armyworm larval damage were to 2 to 3 times greater in the second and third plantings than the greatest rating in the first planting for most cultivars and at both 30- and 55-d post planting samples. Cultivars with the greatest damage ratings varied among plantings, reaching a maximum of 7.8 (30-d) and 7.2 (55-d) for #9 Gambella in the second and third plantings, respectively. Della consistently had the lowest or among the lowest ratings in all 3 plantings.

Sugarcane borer was the only borer species found within sweet sorghum ratoon stalks. Damage to plant crop stalks was < 0.1%. The mean number of internodes on ratoon crop stalks varied significantly across the cultivars ranging from 6.7 to 12.5 per stalk in the first planting and 5.4 to 11.2 in the second planting (Table 2). Percentages of bored internodes ranged from 0 to 2.3% and 0 to 1.3% in the first and second plantings, respectively. Cultivars with the smallest percentages of bored internodes and bored stalks varied between the 2 planting dates, but the levels were among the greatest (> 10%) for Sugar Drip and Sugar T in both plantings.

The panicles (seed heads) were colonized by the most diverse group of insects in the study. Herbivores, predators, and parasitoids were encountered on most seed heads. Sorghum midge *Contarinia sorghicola* (Coquillett) (Diptera: Cecidomyiidae), a common pest of grain sorghum worldwide, was not observed in any of the cultivars during this trial. Pollen from the flowers and sugary exudates exuded from seeds infected with ergot fungus attracted many pollen feeding, predatory and parasitic Hymenoptera species, as well as the banded cucumber beetle *Diabrotica balteata* LeConte (Coleoptera: Chrysomelidae) and green June beetle *Cotinis nitida* (L.) (Coleoptera: Scarabaeidae). Corn earworm *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) and sorghum webworm *Nola cereella* (Bosc) (Lepidoptera: Nolidae) larvae were found grazing in the panicles, but observations indicated that most did not complete development due to predation by the earwig *Doru taeniatum* (Dohrn) (Dermaptera: Forficulidae), red imported fire ants *Solenopsis invicta* Buren (Hymenoptera: Formicidae), and paper wasps (Hymenoptera: Vespidae). Twelve stink bug and one leaf-footed bug species were found feeding on the developing seeds in the panicles (Table 3). The majority of seeds bore the feeding spots from these piercing sucking feeders. The southern green stink bug *Nezara viridula* (L.), the rice stink bug *Oebalus pugnax* (F.), and *Thyanta perditor* (F.) (Heteroptera: Pentatomidae) were the 3 most commonly collected stink bugs making up 29.7, 20.3 and 17.7% of the total stink bugs collected, respectively. Southern green stink bugs were common at the beginning of the harvest period, tapered off and then peaked again before the end of the harvest period. The rice stink bug was captured in similar numbers throughout the first 2 months of harvest. *Thyanta perditor* was very common in the first month of harvest dates before almost disappearing from later counts. The leaf-footed bug *Leptoglossus phyllopus* L. (Hemiptera: Coreidae) was observed on seed heads throughout the trial, but was most common in the first month of the harvest period.

Agronomic Analyses

Planting date, cultivar and their interaction were highly significant ($P < 0.002$) sources of variation in the ANOVA models for all measured yield metrics (Table 4). Therefore, the data were separated and re-analyzed by planting date for each of the yield metrics (Tables 5, 6 and 7).

In the first planting, days to harvest ranged from 91 to 148 d with an average of 116 d (Table 5). The days to harvest ranged from 87 to 153 d in the second planting, with an average of 117 d (Table 6). In the third planting, days to harvest ranged from 84 to 131 d, with an average of 112 d (Table 7). The growth duration can be divided into 3 groups: early maturing (about 90 d), middle maturing (about 120 d) and late maturing (> 135 d). In this study, early maturing cultivars were 'Dale', 'Della', 'Simon' and 'Sugar Drip'. Late maturing cultivars were 'Merissa (Bari)', 'Dobbs', 'U.G. 6.7', and 'Ifube #18'.

Overall fresh weight was greatest in the first planting and decreased significantly with each subsequent planting (Table 4). Mean fresh weights among cultivars ranged from 27.0 to 118, 34 to 109, and 20 to 69 Mg ha^{-1} in the first, second and third plantings, respectively. Fresh weight was 19% smaller in the second than first planting and nearly 40% smaller in the third than second plantings. Cultivar had a significant ef-

Table 2. Mean[1] ± SEM percentage of 1st ratoon sweet sorghum internodes and stalks bored by sugarcane borer.

Cultivar	31 Mar planting				4 May planting			
	N	No. internodes per stalk	% bored internodes	% bored stalks	N	No. internodes per stalk	% bored internodes	% bored stalks
'Dale'	122	9.3 ± 0.1 cd	0.8 ± 0.3 abc	6.6 ± 2.3 a-d	120	6.4 ± 0.2 gh	1.3 ± 0.7 a	4.2 ± 1.8 a-f
'Della'	121	7.8 ± 0.2 ef	1.1 ± 0.4 abc	6.6 ± 2.3 a-d	120	5.4 ± 0.1 i	0.3 ± 0.3 bc	1.7 ± 1.2 def
'Simon'	124	7.5 ± 0.1 fg	1.8 ± 0.6 abc	8.9 ± 2.6 a-d	120	6.1 ± 0.2 hi	0.4 ± 0.2 bc	2.5 ± 1.4 c-f
'Sugar Drip'	120	6.7 ± 0.1 g	2.2 ± 0.6 a	11.7 ± 2.4 abc	120	7.0 ± 0.1 fg	1.3 ± 0.5 a	8.3 ± 2.5 a
'Keller'	120	7.3 ± 0.2 fg	2.3 ± 0.7 a	10.0 ± 2.8 a-d	120	9.5 ± 0.1 bcd	0.2 ± 0.1 bc	1.7 ± 1.2 def
'Sile All II'	123	11.0 ± 0.2 b	2.0 ± 0.6 ab	12.2 ± 3.0 ab	120	8.6 ± 0.2 e	0.5 ± 0.3 abc	3.3 ± 1.7 b-f
'Sugar T'	124	9.8 ± 0.2 c	2.0 ± 0.5 ab	13.7 ± 3.1 a	120	9.3 ± 0.2 b-e	1.0 ± 0.3 ab	7.5 ± 2.4 ab
'Brandes BG'	120	9.1 ± 0.2 cd	0.5 ± 0.3 abc	3.3 ± 1.6 bcd	120	7.6 ± 0.2 f	0.7 ± 0.3 abc	5.8 ± 2.2 a-d
'#9 Gambela'	120	8.7 ± 0.2 de	0.3 ± 0.2 bc	1.7 ± 1.2 cd	120	9.1 ± 0.1 cde	0.6 ± 0.3 abc	5.0 ± 2.0 a-e
'Theis'	120	9.5 ± 0.2 cd	0.7 ± 0.3 abc	4.2 ± 1.8 a-d	120	10.0 ± 0.2 b	0.0 ± 0 c	0.0 ± 0 f
'Brandes'	119	9.4 ± 0.2 cd	0.9 ± 0.4 abc	5.0 ± 0.2 a-d	120	9.1 ± 0.2 cde	0.4 ± 0.2 bc	4.2 ± 1.8 a-f
'M81-E'	120	9.8 ± 0.2 c	0.6 ± 0.3 abc	5.0 ± 2.0 a-d	126	9.6 ± 0.1 bcd	0.6 ± 0.2 abc	5.6 ± 2.1 a-e
'Top 76-6'	120	9.8 ± 0.2 c	0.5 ± 0.3 abc	4.2 ± 1.8 a-d	120	8.7 ± 0.2 e	0.6 ± 0.3 abc	4.2 ± 1.8 a-f
'Grassl'	—		—	—	121	9.7 ± 0.2 bc	0.2 ± 0.2 bc	1.7 ± 1.2 def
'U.G. 6.7'	120	12.1 ± 0.3 a	0.0 ± 0 c	0.0 ± 0 d	120	9.4 ± 0.1 b-e	0.6 ± 0.2 abc	4.2 ± 1.8 a-f
'Merissa (Bari)'	120	12.5 ± 0.3 a	0.2 ± 0.1 bc	1.7 ± 1.2 cd	121	11.2 ± 0.2 a	0.2 ± 0.1 bc	2.5 ± 1.4 c-f
'Dobbs'	120	9.0 ± 0.2 cd	0.3 ± 0.2 bc	1.7 ± 1.2 cd	120	8.9 ± 0.2 de	0.1 ± 0.1 c	0.8 ± 0.8 ef
'Ifube #18'	120	9.1 ± 0.1 cd	0.1 ± 0.1 c	0.8 ± 0.8 d	120	9.2 ± 0.1 cde	0.8 ± 0.3 abc	6.7 ± 2.3 abc
$F; p > F$[2]		61.385; < 0.0001	4.19; < 0.0001	4.26; < 0.0001		82.14; < 0.0001	1.66; 0.448	1.77; 0.0267

[1]Means in a column followed by the same letter are not significantly different (LSD, $p = 0.05$).
[2]Analysis of variance for cultivar effects by planting date (Proc GLM, SAS 2011). 1st planting df = 17, 2105; 2nd planting df = 17, 2096.

TABLE 3. PROPORTION OF PENTATOMIDAE AND COREIDAE (HEMIPTERA) SPECIES CAPTURED ON PLANT CROP SWEET SORGHUM HEADS BY HARVEST DATE ACROSS CULTIVARS.

	Season total		Harvest date (day of year)										
Species	no.	%	181	190	211	222	225	228	238	245	258	277	291
Pentatomidae													
Chinavia hilare (Say)	18	1.5	4.5	0.5	1.0	0	0	0	0	0	0	11.1	6.7
Chlorochroa senilis (Stal)	9	0.7	1.5	0	1.5	0	0	0	0	0	0	0	0
Euschistus quadrator Rolston	8	0.6	1.5	1.6	0.3	0	4.3	0	0	0	0	0	0
Euschistus ictericus (L.)	132	10.7	10.1	6.0	17.6	0	26.1	9.7	6.7	3.3	0	0	0
Euschistus obscurus (Palisot de Beauvois)	5	0.4	0.5	0.5	0.3	0	0	1.0	0	0	0	0	0
Nezara viridula (L.)	367	29.7	34.7	6.6	47.1	0	52.2	10.7	34.7	16.7	50.0	63.0	80
Oebalus insularis Stal	37	3.0	0.5	7.7	1.0	2.9	0	6.8	0	6.7	0	0	0
Oebalus pugnax (Fabricius)	250	20.3	1.5	21.3	8.2	52.9	0	49.0	26.7	36.7	31.3	7.4	0
Oebalus ypsilongriseus (DeGeer)	104	8.4	0	7.1	1.3	42.9	0	19.4	2.7	33.3	12.5	3.7	6.7
Thyanta custator custator (Fabricius)	13	1.1	5.0	1.6	0	0	0	0	0	0	0	0	0
Thyanta perditor (Fabricius)	219	17.7	32.7	44.8	18.2	0	4.3	0	0	0	0	0	0
Mormidea pama Rolston	13	1.1	0	0	0	1.4	0	0	16.0	0	0	0	0
Coreidae													
Leptoglossus phyllopus (L.)	59	4.8	7.5	2.2	3.6	0	13.0	3.4	12.0	3.3	6.3	14.8	6.7
Overall and harvest date total no.	1234[1]		199	183	391	70	23	206	75	30	16	27	15

[1]Includes 1 unidentified *Euschistus* sp.

TABLE 4. ANALYSIS OF VARIANCE FOR PLANT CROP SWEET SORGHUM YIELD.

Yield metric	Source of variation[1]	F[2]	$p > F$	planting date	LS Means ± SEM[3]
Fresh wt	Planting	120.52	< 0.0001	31 Mar	79.1 ± 1.83 a
(Mg ha^{-1})	Cultivar	16.20	< 0.0001	4 May	65.3 ± 1.85 b
	P × V	2.58	< 0.0001	10 Jun	39.4 ± 1.83 c
Dry wt	Planting	97.02	< 0.0001	31 Mar	19.5 ± 0.53 a
(Mg ha^{-1})	Cultivar	20.68	< 0.0001	4 May	16.5 ± 0.53 b
	P × V	2.62	< 0.0001	10 Jun	9.4 ± 0.53 c
Juice extract	Planting	13.95	< 0.0001	31 Mar	55.0 ± 0.41 a
(%)	Cultivar	63.09	< 0.0001	4 May	53.8 ± 0.42 b
	P × V	2.39	0.0002	10 Jun	51.9 ± 0.41 c
Brix	Planting	8.33	0.0004	31 Mar	127.2 ± 1.23 a
(g kg^{-1})	Cultivar	20.42	< 0.0001	4 May	126.0 ± 1.24 a
	P × V	4.01	< 0.0001	10 Jun	120.5 ± 1.23 b
Sugar yield	Planting	118.06	< 0.0001	31 Mar	4.02 ± 0.10 a
(Mg ha^{-1})	Cultivar	16.41	< 0.0001	4 May	3.22 ± 0.10 b
	P × V	2.34	0.0002	10 Jun	1.90 ± 0.10 c
Potential	Planting	118.06	< 0.0001	31 Mar	2546 ± 65.8 a
ethanol	Cultivar	16.41	< 0.0001	4 May	2036 ± 66.5 b
(L ha^{-1})	P × V	2.34	0.0002	10 Jun	1200 ± 65.8 c

[1]P = planting date (df = 2), V = sweet sorghum cultivar (df = 17), P × V = interaction (df = 34), error df = 161.
[2]Proc GLM (SAS 2011).
[3]Least squared means by planting date, means for each yield metric followed by the same letter are not significantly different (LSD, a = 0.05).

fect on fresh weight in all 3 plantings (Tables 5, 6 and 7), but fresh weight variation among cultivars decreased from the first to third planting. Early maturing cultivars, such as 'Dale', 'Della', 'Simon' and 'Sugar Drip', produced low fresh biomass yield relative to the majority of middle and late maturing cultivars tested. Cultivars with consistently greater fresh weight at harvest than other cultivars at each planting were 'Brandes', 'Brandes BG', 'Grassl', 'Top 76-6', and 'M81-E'.

Dry weight (Mg ha^{-1}) also decreased overall from the first to third plantings (Table 4). Dry weight ranged from 5.5 to 34.6, 8.0 to 27.2, and 4.1 to 15.8 Mg ha^{-1} in the first, second and third plantings, respectively. While there was only a 14% reduction in dry weight between the first and second plantings, dry weight was reduced another 43% from the second to third plantings. A significant effect of cultivar on dry weight was observed at all planting dates (Tables 5, 6 and 7). At least 14 of the 19 cultivars in each planting had dry to fresh weight ratios > 20%. Ratios of these 2 metrics were > 25% (range 25.8 to 38.1) at all planting dates in the late maturing cultivars 'Merissa (Bari)', 'Grassl', 'Dobbs', 'Ifube #18' and 'U.G. 6.7', with ratios consistently greatest in 'Merissa (Bari)'. Cultivars with dry to fresh weight ratios < 19% included 'Sile All II' (1st planting), 'Dale' and 'Sugar Drip' (2nd planting), 'Brandes' and 'Simon' (3rd planting), and 'Sugar T' (1st and 3rd plantings).

Planting date affected juice extraction percentage (Table 4), with a slight but significant reduction from 55.0 to 51.9 % observed between the first and third plantings. Cultivar had a significant effect on juice extraction at all 3 planting dates (Tables 5, 6 and 7). The 5 PI lines with the greatest dry weights generally also had the lowest percentage juice extraction at all planting dates (range 34 to 53%). Cultivars with greater percentage juice extraction in at least 2 of the 3 planting dates generally also had the shortest DTH, including 'Dale', 'Sugar T', 'Sugar Drip', and 'Della' (range 56 to 63%).

Brix values were not significantly different between the first and second plantings, but both were significantly greater than the third planting (Table 4). Variation among the cultivars was greatest in the first planting (95 to 158 g kg^{-1}) followed by the second planting (93 to 153 g kg^{-1}). Brix values varied significantly among cultivars in all 3 plantings (Tables 5, 6 and 7). 'Keller' presented the greatest brix values in all 3 plantings (142 to 158 g Kg^{-1}). 'Dale', 'Simon', 'Sugar Drip', 'Theis' and 'Top 76-6' returned among the greatest brix values in the trial.

Sugar yield dropped significantly through the season with each planting date (Table 4). Values

TABLE 5. MEAN[1] ± SEM PLANT CROP YIELD FOR SWEET SORGHUM PLANTED 31 MAR 2010 AT BELLE GLADE, FLORIDA.

Cultivar	d to harvest	fresh wt (Mg ha^{-1})	dry wt (Mg ha^{-1})	Juice extraction (%)	Brix (g kg^{-1})	Sugar yield (Mg ha^{-1})	Potential ethanol (L ha^{-1})
'Dale'	91	46.2 ± 6.8 fg	9.6 ±1.5 hij	64.4 ± 0.6 a	136.4 ± 3.9 bcd	3.1 ± 0.5 def	1944 ± 312 def
'Della'	91	54.5 ± 4.8 efg	11.6 ± 1.0 g-j	61.4 ± 0.4 abc	126.5 ± 2.2 def	3.2 ± 0.3 def	2002 ± 155 def
'Simon'	91	27.0 ± 3.4 g	5.5 ± 0.6 j	62.0 ± 1.5 ab	140.5 ± 4.1 bc	1.8 ± 0.2 f	1116 ± 136 f
'Sugar Drip'	91	33.6 ± 2.3 g	7.1 ± 0.6 ij	62.3 ± 0.8 ab	139.8 ± 2.0 bc	2.2 ± 0.1 ef	1384 ± 86 ef
'Keller'	100	66.9 ± 6.0 def	14.8 ± 1.4 e-i	58.7 ± 0.9 a-d	158.6 ± 5.0 a	4.7 ± 0.4 abc	2957 ± 267 abc
'Sile All II'	100	78.6 ± 5.4 cde	14.2 ± 1.5 f-h	57.9 ± 0.8 bcd	95.1 ± 5.7 i	3.2 ± 0.3 de	2051 ± 164 de
'Sugar T'	100	108.4 ± 8.4 ab	19.5 ± 1.5 c-g	64.3 ± 0.7 a	100.4 ± 2.6 hi	5.3 ± 0.5 abc	3334 ± 324 abc
'Brandes BG'	120	93.5 ± 5.0 a-d	22.0 ± 1.5 c-f	54.7 ± 0.6 ef	138.5 ± 2.3 bc	5.3 ± 0.2 ab	3354 ± 154 ab
'#9 Gambela'	120	81.2 ± 8.4 b-e	17.5 ± 2.1 d-h	59.8 ± 0.9 a-d	115.7 ± 4.2 fg	4.2 ± 0.4 bcd	2647 ± 252 bcd
'Theis'	120	91.0 ± 7.7 a-d	21.2 ± 2.2 c-f	60.0 ± 0.9 a-d	141.8 ± 2.5 bc	5.8 ± 0.5 a	3664 ± 287 a
'Brandes'	121	86.6 ± 9.9 bcd	17.7 ± 2.3 d-h	55.9 ± 0.4 cdd	130.5 ± 3.4 cde	4.7 ± 0.6 abc	2994 ± 350 abc
'M81-E'	121	99.3 ± 3.4 abc	22.8 ± 0.5 cde	56.7 ± 1.0 bcd	137.9 ± 3.8 bc	5.8 ± 0.2 a	3675 ± 100 a
'Top 76-6'	121	78.4 ± 6.3 cde	17.6 ± 1.7 d-h	56.0 ± 1.9 cd	143.3 ± 3.5 b	4.7 ± 0.3 abc	2968 ± 198 abc
'Grassl'	135	118.1 ± 23.9 a	34.6 ± 7.9 a	49.7 ± 1.7 ef	136.6 ± 5.7 bcd	6.1 ± 1.3 a	3846 ± 831 a
'U.G. 6.7'	135	89.0 ± 8.8 bcd	31.7 ± 2.4 ab	40.6 ± 4.3 gh	109.6 ± 4.3 gh	2.9 ± 0.1 def	1826 ± 90 def
'Merissa (Bari)'	148	83.6 ± 7.5 bcd	31.9 ± 3.8 ab	36.1 ± 2.5 h	122.8 ± 2.0 ef	2.8 ± 0.3 def	1755 ± 173 def
'Dobbs'	148	86.5 ± 14.3 bcd	25.3 ± 4.7 bcd	43.6 ± 1.6 g	104.2 ± 6.4 hi	2.9 ± 0.5 def	1857 ± 301 def
'Ifube #18'	148	101.9 ± 17.1 abc	27.0 ± 4.2 abc	45.5 ± 5.5 fg	110.9 ± 4.7 gh	3.9 ± 0.8 cd	2459 ± 519 cd
$F; p > F$[2]		6.42; < 0.0001	8.48; < 0.0001	17.69; < 0.0001	18.98; < 0.0001	7.11; < 0.0001	7.11; < 0.0001

[1]Means in a column followed by the same letter are not significantly different (LSD, a = 0.05).
[2]Analysis of variance for cultivar effects by planting date, df = 17, 54 (Proc GLM, SAS 2011).

TABLE 6. MEAN[1] ± SEM PLANT CROP YIELD FOR SWEET SORGHUM PLANTED 4 MAY 2010 AT BELLE GLADE, FLORIDA.

Cultivar	d to harvest	fresh wt (Mg ha^{-1})	dry wt (Mg ha^{-1})	Juice extraction (%)	Brix (g kg^{-1})	Sugar yield (Mg ha^{-1})	Potential ethanol (L ha^{-1})
'Dale'	98	40.2 ± 2.3 gh	8.0 ± 0.2 fg	62.9 ± 0.9 a	139.2 ± 3.1 b	2.6 ± 0.1 f	1668 ± 90 f
'Della'	98	43.9 ± 5.1 fgh	9.5 ± 1.1 efg	60.8 ± 1.3 ab	120.5 ± 0.5 de	2.4 ± 0.3 f	1529 ± 187 f
'Simon'	67	37.7 ± 0.9 h	8.4 ± 0.3 efg	55.5 ± 0.5 cde	140.0 ± 2.9 b	2.2 ± 0.1 f	1387 ± 9 f
'Sugar Drip'	67	39.9 ± 6.2 gh	8.5 ± 1.3 efg	57.9 ± 0.8 bc	141.9 ± 3.3 ab	2.4 ± 0.4 f	1547 ± 222 f
'Keller'	98	34.2 ± 2.7 h	7.5 ± 0.5 g	61.6 ± 1.2 ab	153.5 ± 1.6 a	2.4 ± 0.3 f	1543 ± 167 f
'Sile All II'	104	48.7 ± 6.5 e-h	11.7 ± 1.7 efg	60.2 ± 1.0 ab	93.9 ± 4.7 g	2.1 ± 0.4 f	1339 ± 229 f
'Sugar T'	104	61.3 ± 1.5 c-f	13.1 ± 0.4 def	59.7 ± 1.1 ab	108.3 ± 2.4 ef	3.0 ± 0.1 ef	1877 ± 17 ef
'Brandes BG'	121	80.9 ± 5.0 bc	20.2 ± 0.6 b	51.8 ± 1.1 e	138.4 ± 4.9 b	4.3 ± 0.2 bc	2734 ± 132 bc
'#9 Gambela'	134	69.7 ± 5.4 bcd	18.4 ± 1.6 bcd	55.4 ± 0.9 cde	129.4 ± 5.4 bcd	3.8 ± 0.5 b-e	2401 ± 294 b-e
'Theis'	121	58.0 ± 4.7 d-g	13.6 ± 1.2 cde	58.0 ± 1.3 bc	120.8 ± 8.1 cde	3.1 ± 0.4 def	1950 ± 261 def
'Brandes'	126	85.9 ± 4.8 b	18.2 ± 1.3 bcd	53.5 ± 1.4 de	119.5 ± 3.4 de	4.1 ± 0.3 bcd	2602 ± 159 bcd
'M81-E'	126	89.5 ± 7.1 b	19.9 ± 1.4 b	57.4 ± 1.6 bcd	118.1 ± 4.2 de	4.5 ± 0.4 b	2871 ± 224 b
'Top 76-6'	126	109.5 ± 16.90 a	23.6 ± 3.9 ab	55.0 ± 1.0 cde	138.5 ± 3.8 b	6.3 ± 1.1 a	4004 ± 705 a
'Grassl'	120	73.5 ± 5.0 bcd	19.0 ± 1.4 bc	53.0 ± 2.0 e	109.2 ± 4.0 ef	3.2 ± 0.4 c-f	2040 ± 243 c-f
'U.G. 6.7'	120	89.1 ± 7.8 b	26.1 ± 1.8 a	45.4 ± 0.9 f	93.2 ± 4.8 g	2.8 ± 0.1 ef	1768 ± 87 ef
'Merissa (Bari)'	146	73.3 ± 7.9 bcd	27.2 ± 3.1 a	37.2 ± 1.2 h	134.4 ± 2.6 b	2.7 ± 0.3 ef	1736 ± 196 ef
'Dobbs'	153	77.1 ± 10.0 bcd	23.8 ± 3.9 ab	41.8 ± 3.8 dg	133.7 ± 8.4 bc	3.1 ± 0.3 def	1983 ± 208 def
'Ifube #18'	153	64.0 ± 8.0 cde	20.4 ± 2.9 b	40.9 ± 1.0 gh	135.2 ± 6.5 b	2.6 ± 0.3 f	1664 ± 196 f
$F; p > F$[2]		9.43; < 0.0001	11.27; < 0.0001	27.52; < 0.0001	12.91; < 0.0001	7.17; < 0.0001	7.17; < 0.0001

[1]Means in a column followed by the same letter are not significantly different (LSD, $\alpha = 0.05$).
[2]Analysis of variance for cultivar effects by planting date, df = 17, 53 (Proc GLM, SAS 2011).

TABLE 7. MEAN[1] ± SEM PLANT CROP YIELD FOR SWEET SORGHUM PLANTED 10 JUNE 2010 AT BELLE GLADE, FLORIDA.

Cultivar	d to harvest	fresh wt (Mg ha^{-1})	dry wt (Mg ha^{-1})	Juice extraction (%)	Brix (g kg^{-1})	Sugar yield (Mg ha^{-1})	Potential ethanol (L ha^{-1})
'Dale'	96	27.8 ± 6.8 d-g	5.6 ± 1.6 fgh	56.8 ± 0.6 abc	127.7 ± 11.5 abc	1.6 ± 0.5 cde	1006 ± 318 cde
'Della'	96	20.1 ± 6.0 g	4.1 ± 1.3 h	57.5 ± 2.3 abc	104.5 ± 9.3 def	0.99 ± 0.3 e	628 ± 216 e
'Simon'	84	22.6 ± 1.7 fg	4.3 ± 0.3 h	54.7 ± 0.8 bc	122.4 ± 4.4 cd	1.1 ± 0.1 de	722 ± 76 de
'Sugar Drip'	84	24.6 ± 1.7 efg	4.9 ± 0.4 gh	55.8 ± 1.0 abc	126.5 ± 4.1 bc	1.1 ± 0.1 de	830 ± 81 de
'Keller'	96	24.5 ± 3.6 efg	5.1 ± 0.9 gh	56.9 ± 1.7 abc	142.6 ± 10.3 ab	1.5 ± 0.3 de	960 ± 188 de
'Sile All II'	96	31.7 ± 7.9 c-g	6.5 ± 1.6 e-h	53.6 ± 1.4 c	95.9 ± 6.1 f	1.3 ± 0.4 de	799 ± 245 de
'Sugar T'	96	41.0 ± 2.4 cde	7.6 ± 0.4 d-h	60.1 ± 2.3 a	95.3 ± 2.0 f	1.8 ± 0.2 b-e	1119 ± 103 b-e
'Brandes BG'	116	45.8 ± 8.4 bc	9.3 ± 1.8 c-g	58.3 ± 1.9 abc	119.1 ± 10.4 cde	2.5 ± 0.7 bc	1598 ± 408 bc
'#9 Gambela'	130	39.4 ± 3.0 c-f	9.2 ± 0.7 c-g	55.6 ± 1.4 abc	123.0 ± 2.9 cd	2.0 ± 0.1 bcd	1272 ± 79 bcd
'Theis'	123	44.5 ± 8.8 bcd	10.2 ± 2.2 c-f	57.1 ± 1.3 abc	101.8 ± 5.4	2.0 ± 0.4 b-e	1245 ± 264 b-e
'Brandes'	123	48.6 ± 5.3 bc	9.6 ± 1.0 b-f	59.3 ± 1.2 ab	121.0 ± 5.5 cd	2.6 ± 0.3 b	1650 ± 179 b
'M81-E'	116	69.8 ± 7.8 a	15.2 ± 1.9 ab	58.8 ± 0.5 ab	120.3 ± 4.4 cde	3.7 ± 0.5 a	2371 ± 331 a
'Top 76-6'	123	67.7 ± 2.3 a	15.8 ± 0.9 a	55.2 ± 1.0 abc	146.4 ± 6.5 a	4.1 ± 0.2 a	2592 ± 112 a
'Grassl'	130	59.5 ± 10.9 ab	15.8 ± 3.8 a	47.6 ± 1.1 d	125.0 ± 7.7 bc	2.7 ± 0.6 b	1732 ± 406 b
'U.G. 6.7'	131	32.3 ± 1.2 c-g	10.6 ± 0.6 b-e	35.2 ± 2.2 e	125.9 ± 5.3 bc	1.1 ± 0.1 de	690 ± 83 de
'Merissa (Bari)'	131	36.1 ± 9.5 c-g	12.0 ± 2.9 a-d	34.8 ± 3.0 e	123.7 ± 5.6 c	1.1 ± 0.3 de	711 ± 178 de
'Dobbs'	130	32.1 ± 3.3 c-g	9.4 ± 1.2 c-g	42.9 ± 2.2 d	116.3 ± 3.7 cde	1.2 ± 0.1 de	754 ± 74 de
'Ifube #18'	131	41.9 ± 2.8 cd	13.9 ± 1.7 abc	34.4 ± 2.8 e	132.0 ± 3.9 abc	1.4 ± 0.2 de	918 ± 140 de
$F; p > F$[2]		6.00; < 0.0001	5.54; < 0.0001	26.16; < 0.0001	4.45; < 0.0001	6.76; < 0.0001	6.76; < 0.0001

[1]Means in a column followed by the same letter are not significantly different (LSD, $\alpha = 0.05$).
[2]Analysis of variance for cultivar effects by planting date, df = 17, 54 (Proc GLM, SAS 2011).

ranged from 1.8 to 6.1, 2.1 to 6.3, and 1.0 to 4.1 Mg ha^{-1} in the first, second and third plantings, respectively. Overall sugar yield was 21% less in the second than first planting and 41% less in the third than first planting. Cultivar again played a significant role in sugar yields in all 3 plantings (Tables 5, 6 and 7). 'Grassl' was at the top of the range of sugar yields in the first planting while 'Top 76-6' was at the top in the second and third plantings. 'Brandes', 'Brandes BG' and 'M-81E' were consistently near the top of the sugar yield range in all 3 plantings.

The estimate of potential ethanol yield per ha follows directly from the sugar yield. As with the other yield metrics, planting date significantly affected potential ethanol yield (Table 4). The yield dropped with each successive planting date, but the 41% drop between the second and third planting dates was the greatest. Potential ethanol yield varied significantly among cultivars in all 3 planting dates (Tables 5, 6 and 7). In the first planting, potential ethanol yield varied 340% from a low of 1,116 liter ha^{-1} in 'Simon' to a high of 3,846 liter ha^{-1} in 'Grassl'. In the second planting, potential ethanol yield ranged from 1,339 liter ha^{-1} in 'Sile All II' to 4,004 liter ha^{-1} in 'Top 76-6'. 'Della' at 628 liter ha^{-1} potentially produced only 24% of that estimated for 'Top 76-6' at 2,592 liter ha^{-1} in the third planting. Potential ethanol yield increased between the first and second plantings in 3 cultivars: 'Dobbs', 'Simon', 'Sugar Drip' and 'Top 76-6'. It is estimated that 9 cultivars in the first planting would produce > 3,000 liter ha^{-1}, 5 cultivars in the second planting would produce > 2,400 liter ha^{-1}, while only 3 cultivars in the third planting would produce > 1,700 liter ha^{-1}. Potential ethanol yield was lower in all cultivars tested in the third planting compared to the first and second plantings.

Discussion

Elasmopalpus lignosellus and *S. frugiperda* produced the greatest amount of foliar damage to sweet sorghum cultivars in this trial. Busoli et al. (1977) determined that *E. lignosellus* preferred sorghum to both maize and sugarcane in field trials in Brazil. Henderson et al. (1973) indicated that *E. lignosellus* was an economically important pest of sweet sorghum in Mississippi where severe damage to main stalks and new shoots reduced stand and yield. Damage to emerging sweet sorghum shoots by *E. lignosellus* reached 26% in M81-E planted 22 Mar 2011 at Belle Glade, Florida (Cherry et al. 2013). We are not aware of economic threshold levels published for *E. lignosellus* on sweet sorghum. Economic injury in sweet sorghum would be tied to its effects on biomass production and level of juice extraction, rather than to grain yield affects. We observed that natural tillering varied significantly among the cultivars tested in our study. Godsey et al. (2012) determined that sweet sorghum biomass yield was significantly affected by row spacing and seeding density. They also stated that the crop has tremendous ability to tiller and compensate for poor stands, so planting density is not as important compared to other crops that do not have the ability to tiller. Cherry et al. (2013) found little to no correlation between sweet sorghum M81-E planting density and damage by *E. lignosellus*. Therefore, stands reduced by *E. lignosellus* damage may be at least partially compensated for by increased tillering. It follows that future economic injury levels for this borer will likely be dependent on cultivar and planting densities.

Most of the published research regarding *S. frugiperda* feeding on *Sorghum* spp. deals with their effects on grain sorghum yield. *Spodoptera* spp. were listed as occasional pests of sorghum by Young & Teetes (1977) in their review of sorghum entomology and Buntin et al. (2009) indicated that insecticide use for fall armyworm control was seldom justified because grain sorghum is very tolerant of defoliation. However, Henderson et al. (1966) determined that whorl stage infestations of *S. frugiperda* resulted in shorter, narrower stalks and reduced grain sorghum yield from 5.4 to 19.6% compared to uninfested plants. Noting the "severe damage" to grain sorghum foliage caused by *S. frugiperda* larvae, McMillian & Starks (1967) found significantly different responses by 30 grain sorghum cultivars to *S. frugiperda* feeding that resulted in more tillers and panicles per plot, but with lower grain yield per head compared to plants without larvae. Martin et al. (1980) reviewed action thresholds for fall armyworm on grain sorghum. Modern published treatment thresholds for whorl infestation by *S. frugiperda* on grain sorghum vary by state: 50% in Kentucky (Johnson 2011), 40 to 60% in Maryland (Dively et al. 2012), 75% in Kansas (Michaud et al. 2012), and 80% in North Carolina (Reisig 2012). Percentage whorl infestation at 33- and 55-d for the second and third plantings in our trials exceeded all these treatment thresholds. Shortened stalks, narrowed stem diameters and increased number of tillers may affect biomass accumulation and juice storage if similar damage was found in sweet sorghum grown for ethanol production. Significant differences in *S. frugiperda* leaf feeding damage also were reported among 15 sweet sorghum cultivars by Anderson & Cherry (1983). They reported "extensive damage" to plants at 60-d post planting with infestation levels ranging from 68 to 100% with 14 of the tested cultivars > 90%. Using a 0 (no damage) to 5 (severe damage) leaf feeding scale, 2 of the cultivars also tested in our current study had the greatest mean damage in their trial: 'M 81-E' (listed as 'Mn 81 E') at 3.66 and 'Brandes' at 3.88. At 2 sites in

Georgia, Duncan & Gardner (1984) determined that insect damage on sweet sorghum, particularly by *S. frugiperda*, was significantly greater on the ratoon than on the plant crop. Using the 0 to 9 visual foliar damage rating scale of Wiseman & Davis (1979) when plants were approximately 35 cm in height, damage ratings at these Georgia trials for 'Brandes' at 3.2, 'Theis' at 2.2, and Keller at 3.3 were significantly lower than ratings in our trial at both 30- and 55-d. Diawara et al. (1992) demonstrated antibiotic resistance to fall armyworm in several converted grain sorghum lines that was correlated with higher total nitrogen in leaves. Significant damage at 30- and 55-d indicates the possibility of prolonged feeding during the vegetative stage.

Diatraea saccharalis is recognized as a serious pest of sweet sorghum (Long & Hensley 1972). Stalk tunneling by *D. saccharalis* lavae reduce uptake of water and nutrients, and result in the death of upper portions of stalks, lodging, and entry of pathogens through tunnel openings (Reagan & Flynn 1986). Lara & Perussi (1984) in Brazil determined that economic injury levels for sweet sorghum were cultivar dependent and ranged from 5 to 11% bored internodes. Fuller et al. (1988) determined that *D. saccharalis* in Louisiana reaches the economic threshold for sweet sorghum when 5% of plants contain small larvae in leaf sheaths, and an economic injury level of 10% of bored internodes. While only 4 of the cultivars in this trial had > 2.0% bored internodes (i.e., 'Keller', 'Sile All II', 'Sugar Drip', and 'Sugar T'), 10% of the harvested stalks had bored internodes, a level much greater than in the sugarcane (< 0.1%) we sampled in surrounding fields. Parasitism by *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) and predation by *S. invicta* and other predacious ant species in sugarcane (Cherry & Nuessly 1992) in southern Florida is thought to play a major role in natural control of *D. saccharalis* populations (Hall & Bennett 1994). Fuller & Reagan (1988) in Louisiana determined that *D. saccharalis* larval survival was greater in sweet sorghum than in sugarcane stems and that more frequent field operations in sweet sorghum compared to sugarcane may be responsible for lower predator populations and subsequently lower borer mortality in sweet sorghum compared to sugarcane. Because adults of this borer are considered to be poor fliers (Fuller & Reagan 1988), ratoon sugarcane fields may serve as important reservoirs for *D. saccharalis* movement into adjacent sweet sorghum fields.

Stink bugs and leaf-footed bugs were found throughout the summer on sweet sorghum panicles in our trial. *Oebalus pugnax*, *Chlorochroa ligala* (Say) and *Nezara viridula* (Heteroptera: Pentatomidae), and *Leptoglossus phyllopus* have all been shown to cause reductions in yield and germination of sorghum seed (Hall & Teetes 1982a, 1982b). *Thyanta perditor*, present at fairly high densities early in our trial, also severely damaged grain yield in several forage and sweet sorghum cultivars (including 'Brandes') in a trial in Jaboticabal, São Paulo, Brazil (Busoli et al. 1984). While stink bugs may cause damage to sweet sorghum seeds, commercial production of sweet sorghum seed is not currently being considered for southern Florida. Stink bug damage to sweet sorghum stalks has not been observed; therefore, they may not cause direct economic injury to production of this crop. Commercial plantings of sweet sorghum could serve as a reservoir or food bridge for stink bugs that could become a pest problem for other commercial crops in Florida, such as rice harvested in late summer and fall planted sweet corn.

Many studies have been conducted worldwide over at least the last 40 yr comparing the effects of planting dates on yield parameters using many of the same cultivars tested in the current study. There was a significant interaction between planting date and cultivars in our study, as well as in studies by Teetor et al. (2011) and Erickson et al. (2011). While Almodares et al. (1997) reported that sweet sorghum planting date had no effect on brix value or sucrose percentage, all yield parameters at the Jun planting date were less than at the Apr and May planting dates. Similar results were reported by Erickson et al. (2011) in Florida, Broadhead (1969) in Mississippi, and Teetor et al. (2011) in Arizona. This yield reduction in Florida was likely due to increased disease pressure, exposure to flooding rains as seedlings, photoperiod effects, and decreased insolation during the growth period due to cloud cover in the later plantings. The highest yielding cultivar in terms of fresh weight and ethanol production varied at each planting date in our study. Some cultivars produced greater fresh weight in the second planting than in the first planting, including 'Simon', 'Sugar Drip' and 'Top 76-6'. 'Sugar T' produced among the top 3 fresh weights in the first planting, but yielded significantly less in the second and third plantings. Total sugar yields in our study for 'Dale' and 'Keller' were lower at all planting dates, but were similar for 'Grassl' at the first planting date, compared to results from Smith & Buxton (1993) in Colorado and Iowa. 'Dale' and 'Sugar Drip' matured to harvest > 40 d sooner in our study than in a study by Parrish et al. (1985) at 3 sites in Virginia. Dry weights in the Virginia study were >30 Mg ha^{-1} higher for these cultivars, but fresh weights for 'Dale' planted in late Mar and May and 'Sugar Drip' planted in May and Jun in Virginia were comparable to those in our study. Field weights for 'Dale', 'M81-E', 'Theis' and 'Top 76-6' were mostly greater at all planting dates (Apr, May, Jun and Jul) in a study in Arizona by Teetor et al. (2011) than in our study, but 'Dale', 'M81-E' and 'Top 76-6' also took 40 to 70 d longer to reach maturity in Arizona than in our study. Interestingly, 'Dale' with the shortest days to harvest in the Arizona study was estimated to produce 2 × more ethanol than in our Florida study. However, the longer maturing cultivars 'Theis' and 'M81-E' were estimated to produce 25 to 50% more ethanol in Florida than in Arizona. Yields for these 2 cultivars were the same in our study at the Apr planting. Yields for 'M81-E' increased significantly, while 'Theis' decreased in our May and Jun plantings, as they did in the Teetor et al. (2011) study at the Jun and Jul plantings. Compared to another recent study by Wortmann et al. (2010) in Nebraska, yields for 'Keller' and 'M81-E' were significantly greater at our first 2 plantings (except for one Nebraska site), but yields for 'Simon' were 2 to 3 times greater in Nebraska than in our study. 'Grassl', the highest yielding cultivar in the first planting, was badly lodged and uprooted in the second planting following a storm and had to be harvested approximately 2 wk early to avoid degradation. This may partly explain the decrease in its observed yield and absence from the top 3 yielding cultivars in the second planting. 'U.G. 6.7' was also badly lodged and uprooted by the same storm and likely would have yielded more had it completed its maturation cycle.

In the most recent study comparing harvest results for sweet sorghum produced on various soil types, Erickson et al. (2011) found lower brix values for cultivars produced on high organic matter Histosols than on other soil types. This may partially explain why brix results reported by most of the workers cited above were greater than in our study. However, greater fresh weights and comparable juice extraction ratios can provide for greater annual yields due to shorter time to harvest for many sweet sorghum cultivars produced on Histosols in southern Florida compared to more northern sites.

None of the cultivars tested in the current study reached the ethanol production level of 4,230 liter ha^{-1} reported to be the amount produced by an average cornfield (Lee & Tollenaar 2007). However, other relevant factors to be considered in comparing energy yields among biofuels include conversion of corn starch to sugar, feedstock longevity, and value of byproducts of the processing (i.e., bagasse and dried distillers grains and solids). Currently, the most important material used to produce ethanol is the sweet sorghum stalk, because it contains the sugar easily converted to ethanol. Although ethanol can be produced from sweet sorghum grain, it requires much more processing to convert starch to glucose and then to ethanol (Almodares & Hadi 2009; Jacques et al. 1999). Grain production from these sweet sorghum cultivars also tends to be low. Ethanol yield from the fiber is difficult to predict (Rains et al. 1993); however, it may be useful as a fuel for distillery and extraction operations. While juice extraction percentage for 'Keller' in our study were >30% greater at all planting dates compared to recent results from India (Ratnavathi et al. 2010), the total sugar and potential ethanol produced were similar between the 2 studies. Percentage juice extraction was >25% higher for 'M81-E', 'Top 76-6' and 'Theis' in the current study than was found by Guigou et al. (2011) in Uruguay.

Our data show that sweet sorghum grows well in southern Florida and provides an alternative crop to rotate with sugarcane and vegetables to produce biofuel for the future. It grows quickly and can be produced from Mar through Nov each year in Florida, complementing the period of local sugarcane harvests from Oct through Apr. Due to reduced yields realized from Jun plantings, and generally lower yields from cultivars maturing in less than 100 d in southern Florida, a wide range of maturities planted during the early spring months will be required to ensure a constant supply of materials between sugarcane harvests for future extraction and distillation facilities. The variation in days to harvest from 90 to 135 d for cultivars with good yield suggest that most of the planting could be completed before the end of the dry period in May to provide for harvests throughout the summer and fall months.

This study demonstrated that grass-feeding insect pests common to Florida readily colonized sweet sorghum during the late spring and summer months in southern Florida. Lesser cornstalk borers, cutworms and wireworms reduced stands in the absence of protective insecticides, particularly in the late Mar planting. The plants were nearly 100% infested with fall armyworms for much of the growing period in the second and third plantings. Increasing the acreage of sweet sorghum during this period will provide a host plant bridge between the vegetable crops grown in the spring and fall and may lead to greater infestations of fall armyworm and stink bugs in fall crops. Sugarcane borer in sweet sorghum did not reach the 5% bored internodes used as the economic threshold level in sweet sorghum and sugarcane. However, several of the cultivars had many times the percentage of bored stalks compared with others, showing the influence of cultivar on infestation. This study has also demonstrated the importance of conducting cultivar trials not only to identify yield differences, but also for insect susceptibility. More research is needed to determine whether stand loss at the seedling stage or defoliation by *S. frugiperda* during vegetative growth results in yield loss to sweet sorghum.

Acknowledgments

We acknowledge R. Gilbert and R. Beiriger (EREC), and Z. Helsel (Dept. Plant Biology and Pathology, Rutgers University, New Brunswick, New Jersey), for their valuable counsel in experimental design, yield evaluations, and manuscript reviews. Assistance with field work and laboratory analysis was provided by I. Alonzo, M. Gonzalez, F. Sosa, and J. Terry (EREC). Publication of this article was funded in part by the University of Florida Open-Access Publishing Fund.

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