

Short Research Article

Biomass Production and Water Economy of Sugarcane and Energy Cane Genotypes Grown in Water-Deficient and Well-Watered Regimes

ABSTRACT

Aims: Study designed to characterize water economy and biomass production of sugarcane and energy cane genotypes grown in a rain-shelter under well-watered and water-stressed conditions during plant cane and two consecutive ratoon cane phases.

Study design: Randomized complete block with 5 replications.

Place and Duration of Study: Texas A&M AgriLife Research and Extension Center near Corpus Christi during 2015 and early 2016.

Methodology: Stem cuts of sugarcane line TCP94-5753 and energy cane lines TUS56 and TUS59 were hand-planted in pots. There were three phases including a water-stressed initial plant cane phase and two sequential well-watered ratoon cane phases. Daily whole-plant transpiration was calculated from hourly pot weight changes measured by electronic loadcells. At the end of each phase, plants were harvested to determine above-ground biomass, partitioned into dry leaf blades biomass and stem dry biomass.

Results: No differences in above-ground dry biomass production or water economy among genotypes after the water-stressed plant cane or the first ratoon cane phase, but TUS56 and TUS59 produced 2.32 and 1.83 times more tillers than the sugarcane genotype, respectively. Cumulative transpiration of TUS56 at the end of this first ratoon cane phase was 17% higher than that of TUS59 and TCP94-5753. At the end of the second ratoon cane phase, total above-ground dry biomass were 60% higher in TUS56 than in the sugarcane genotype, but not different from those in TUS59. Cumulative whole-plant transpiration during this phase was about 88% higher for the energy cane genotypes.

Conclusion: Genotypes performed equally in above-ground biomass production and water economy after exposure to water deficits during the initial plant cane phase. No differences in biomass production were observed after the well-watered first ratoon cane phase among genotypes, but TUS56 exhibited more leafiness and transpired more than TUS59 and the sugarcane genotype, and both energy cane lines produced more tillers than the sugarcane.

Keywords: *Water economy; plant water use; biomass production; water use efficiency; drought tolerance; sugarcane vs energy cane.*

1. INTRODUCTION

The use of crop species that have high efficiency of conversion of solar energy into biomass, such as grasses like sugarcane (*Saccharum* spp) that use the C4 photosynthetic pathway, have a great potential to be used as sources of biomass for the production of biofuels [1,2]. Energy cane (*Saccharum spontaneum*), that is a new type of cane with high fiber yield initially developed by breeding programs in Louisiana and Puerto Rico [3,4] appeared as an important alternative to sugarcane (*Saccharum officinarum*) as a source of biomass for the production of biofuels [5,6]. Other advantages of *S. spontaneum* over *S. officinarum* include

its ability to produce more stalks, an abundant root system [1], and a stronger ratooning ability [7]. Furthermore, since soil water availability is a dominant factor affecting plant productivity, with drought being the most dominant environmental factor limiting yields and irrigation being the common practice to maintain biomass production [8,9], comparative evaluations of sugarcane and energy cane genotypes would benefit from characterizing the responses of these species' to contrasting soil water regimes.

While plants growing under plentiful soil water regimes exhibit unlimited transpiration, photosynthesis and growth rates, plants that are exposed to soil water deficits commonly exhibit decreased expansive growth (particularly leaf area and stem elongation), decreased transpiration and photosynthesis through stomata closure, and, due to the latter, decreased biomass production [10,11,12]. Plant exposure to soil water deficits can also increase water use efficiency as transpiration is decreased more than photosynthetic carbon uptake [10,11]. This is particularly notable in C4 species such as sorghum and sugarcane species. Substantial genotype-by-environment interactions have been repeatedly found in standard crop field tests, including sugarcane, conducted under naturally or managed variable soil water regimes. Sugarcane genotype-by-environment interactions have been reported in relation to leaf elongation rate and leaf senescence [13] and stomatal resistance [14] and biomass production [15]. A recent study designed to characterize water economy of a group of sugarcane transgenic lines grown in a rain-sheltered under well-watered and water-stressed conditions allowed to identify genotypes differing in water use efficiency, genotypes that were more water-prodigious or water-conservative when soil water was not limiting, as well as other genotypes that were less tolerant to water stress than their respective non-transgenic genetic backgrounds [16]. However, no reports have been found in relation to a simultaneous comparative characterization and quantification of the whole-plant water economy and growth of sugarcane and energy cane genotypes under both well-watered and water-deficient water regimes.

The objective of this study was to characterize and quantify the whole-plant water economy and above-ground biomass production of one sugarcane and two energy cane genotypes grown in a rain-shelter under well-watered and water-stressed conditions during plant cane and two consecutive ratoon cane phases.

2. MATERIAL AND METHODS

The study was conducted at the Drought Tolerance Laboratory at the Texas AgriLife Research and Extension Center near Corpus Christi from the spring of 2015 to winter of 2016. This facility consists of two joined greenhouse structures modified to operate as rain shelters housing a large number of electronic mini lysimeters capable of measuring continuous whole-plant transpiration under controlled watering regimes. Computerized systems monitored whole-plant plant water use and controlled watering with a nutrient solution.

Germinated stem cuts of sugarcane line TCP94-5753 and energy cane lines TUS56 and TUS59 supplied by Dr. J. Da Silva's Sugarcane Variety Improvement Program at the Texas AgriLife Research and Extension Center in Weslaco were hand-transplanted in large 13.5-L pots on March 5, 2015. The soil medium consisted of fritted clay, which is known by its high water holding capacity [17]. Pots were uniformly filled with 11.4 L of the soil medium to minimize maximum soil water availability as a variable factor affecting plant growth and plant water economy. Drained water holding capacity of pots was 4.1 L, of which about 60% (2.46 L) was available to plants. Upon transplanting, the soil surface was covered with aluminum foil to minimize soil evaporation but leaving an opening around the emerged shoots. Tiny holes were punctured in the aluminum foil to allow infiltration and uniform surface distribution

of irrigation water. Five fairly uniform plants of the sugarcane line and of each of the two energy cane lines (a total of fifteen plants) were spatially arranged to conform a 5-replication randomized complete block experimental design. The fifteen potted plants were each permanently hanged from a weighing electronic loadcell for continuous measurement of whole-plant water use. All experimental plants were individually irrigated daily to excess with a modified Hoagland solution made up with purified city water from the post-transplant juvenile stage until the start of the first phase of the study on May 13, 2015. Pots were individually irrigated using a spout-based distribution system to secure a uniform application of water.

The study was designed in three growth phases, namely plant cane, first ratoon cane, and second ratoon cane. In the plant cane phase (13 May – 08 September, 2015), all three experimental lines were subjected to a moderate water deficit by limiting daily irrigation from the pre-study excess irrigation level to 1 min d^{-1} at 650 L min^{-1} (this irrigation flow rate was maintained throughout the length of the study). This procedure, which allowed for a slow field-like onset of water stress on the test plants, was set to study the responses of the experimental lines to drought. At the end of the first plant cane phase, above-ground plant parts were harvested in all pots for tillering and dry biomass measurements. Upon harvesting, the first ratoon cane phase (10 September – 09 December 2015) was initiated on September 10th and continued until December 9th, 2015, when ratoon cane plants harvested for above-ground dry biomass and tillering measurements. During this second phase of the study, the first ratoon cane plants were irrigated in excess, initially 3 min d^{-1} and later 5 min d^{-1} , as plants increased in size. Upon harvesting the first ratoon cane phase, the third phase of the study (second ratoon cane) was initiated on December 23rd, 2015 and continued until February 23rd, 2016, when above-ground plant parts were harvested for biomass measurements. During this second ratoon cane phase, plants were also irrigated in excess. This procedure of exposing the experimental lines to a well-watered regime during the second and third phases of the study was set to assess their growth potential during each of two successive ratoon cane phases.

Harvested above-ground plant biomass was dissected into leaf blades and tiller stems, the latter including leaf sheaths, and their dry biomass measured. The tillering characteristics were assessed by counting the number of tillers, measuring their total length, and calculating their average specific stem length (total dry tiller biomass/total length).

Pot weights were measured continuously at 10-min intervals using a computerized automated system. This data was used to calculate the daily whole-plant transpiration (DWPT) as the 24-hr cumulative pot weight differences between consecutive hours. This method removed almost all interference of plant growth in the calculation of plant transpiration. The total cumulative whole-plant transpiration (CDWPT) during each of the three phases of the study was calculated for each pot as the sum of the daily whole-plant transpiration values. Cumulative whole-plant transpiration per unit leaf mass was also calculated to further characterize the leaf transpiration for each of the experimental lines. The experimental lines were also compared in terms of a nominal water use efficiency value (above-ground biomass/cumulative whole-plant transpiration).

Weather conditions during the experimental period are best summarized by the daily variation in reference potential evapotranspiration (RPET) calculated from hourly air temperature and humidity, solar radiation and wind speed measured by an automated field weather station located approximately 100 m east of the Drought Tolerance Laboratory (Fig. 1). Cumulative RPET (CRPET) was calculated for each of the three phases of the study. Linear regressions of CDWPT on CRPET were obtained for distinct sub-periods in all three phases of the study to advance the interpretation of whole-plant transpiration responses to

the applied water regimes. Experimental data (sums, averages, standard deviations, and coefficients of variation) were summarized using Excel (Microsoft Corporation, Redmond, WA) and statistical analyses including ANOVA, mean separations, and contrasts were performed using JMP (SAS Institute, Cary, NC).

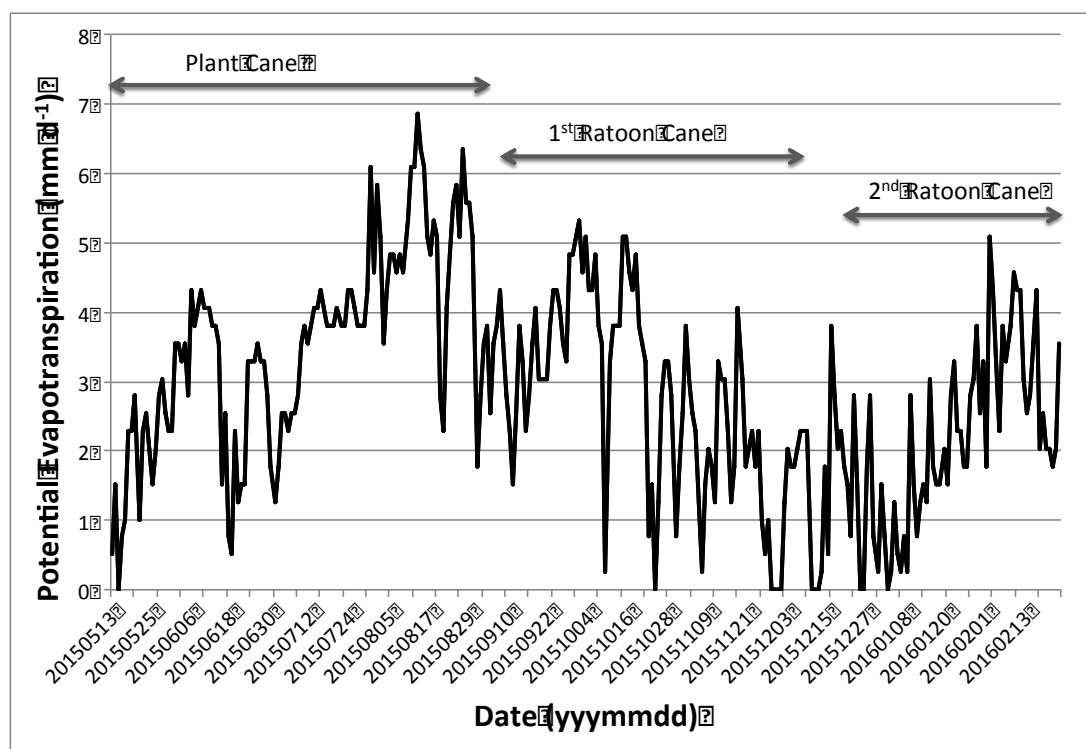
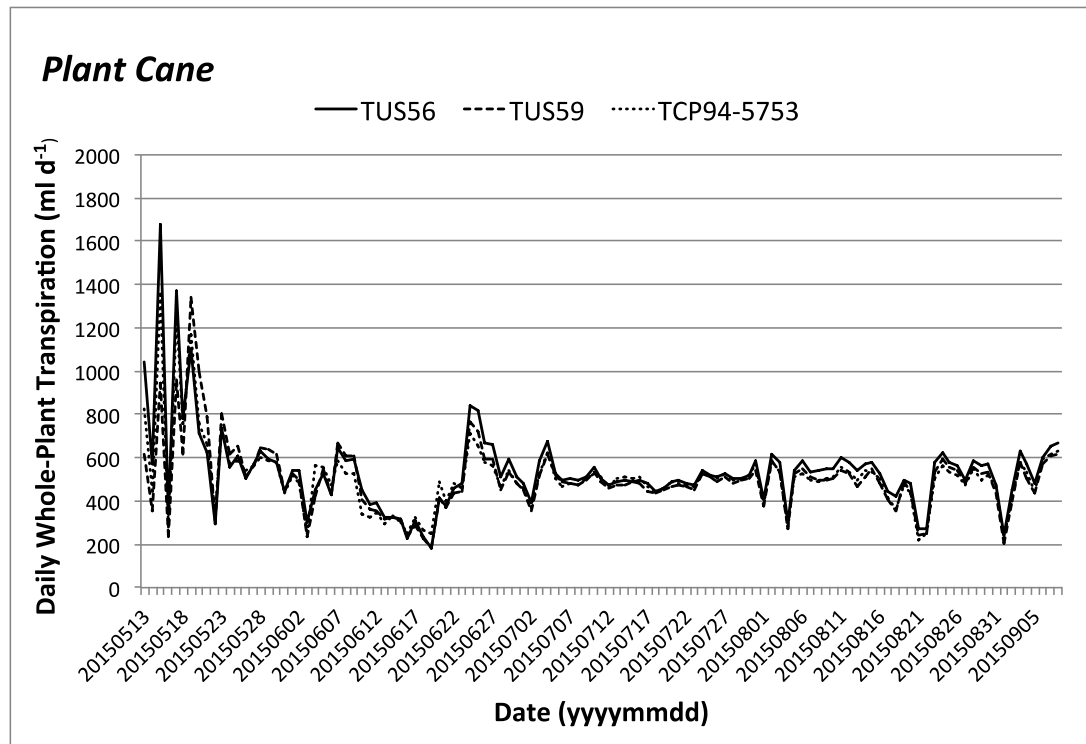


Figure 1. Progression of daily reference potential evapotranspiration throughout the three phases of the study. Data source: The Crop-Weather Program for South Texas available online at <http://cwp.tamu.edu>.

3. RESULTS AND DISCUSSION

3.1 Phase 1 of study: Plant cane under water-deficient conditions

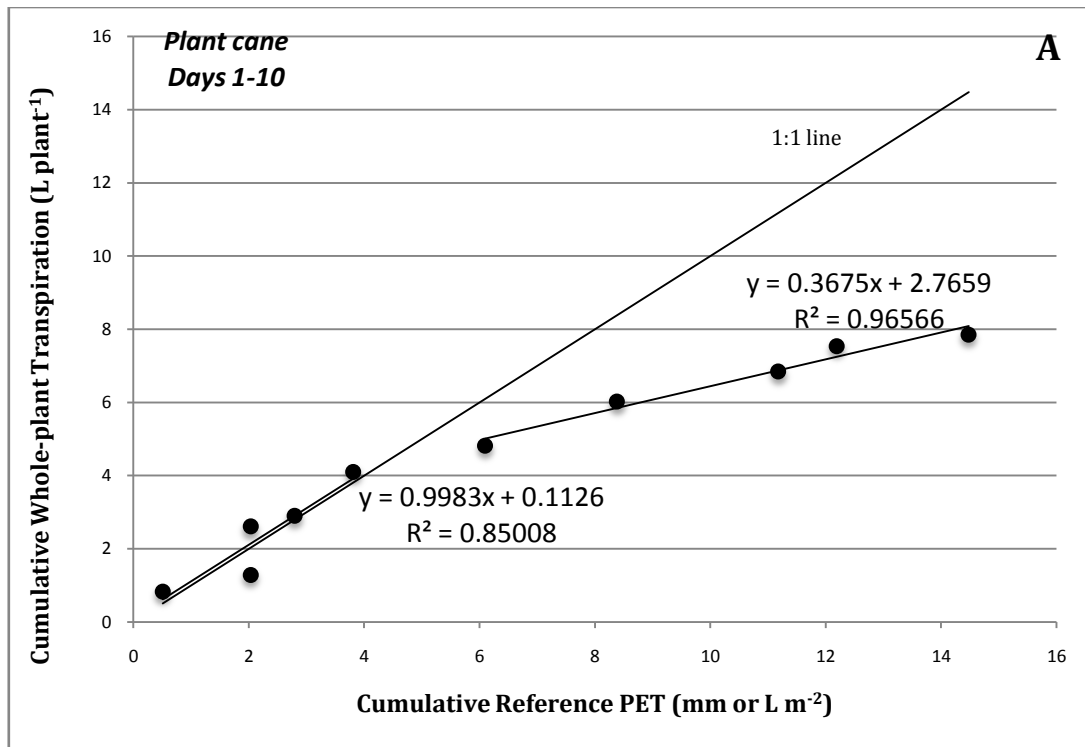
Day-to-day variation of daily whole-plant transpiration observed during the plant cane phase under moderate water-deficient conditions (Fig. 2) resulted from: a) normal day-to-day variation in weather conditions, b) progressive variations in leaf area per plant, including production of new leaves, leaf expansive growth, and leaf senescence, and c) progressive variations in leaf conductance leading to declines in leaf transpiration due to stomatal closure. Progression of daily RPET during phase 1 (Fig. 1) was characterized by the normal day-to-day variation and an overall increasing trend throughout the 99-day length of this first phase, which included three short periods of decreased atmospheric evaporative demand, two of them during the middle and one toward the end of the phase.



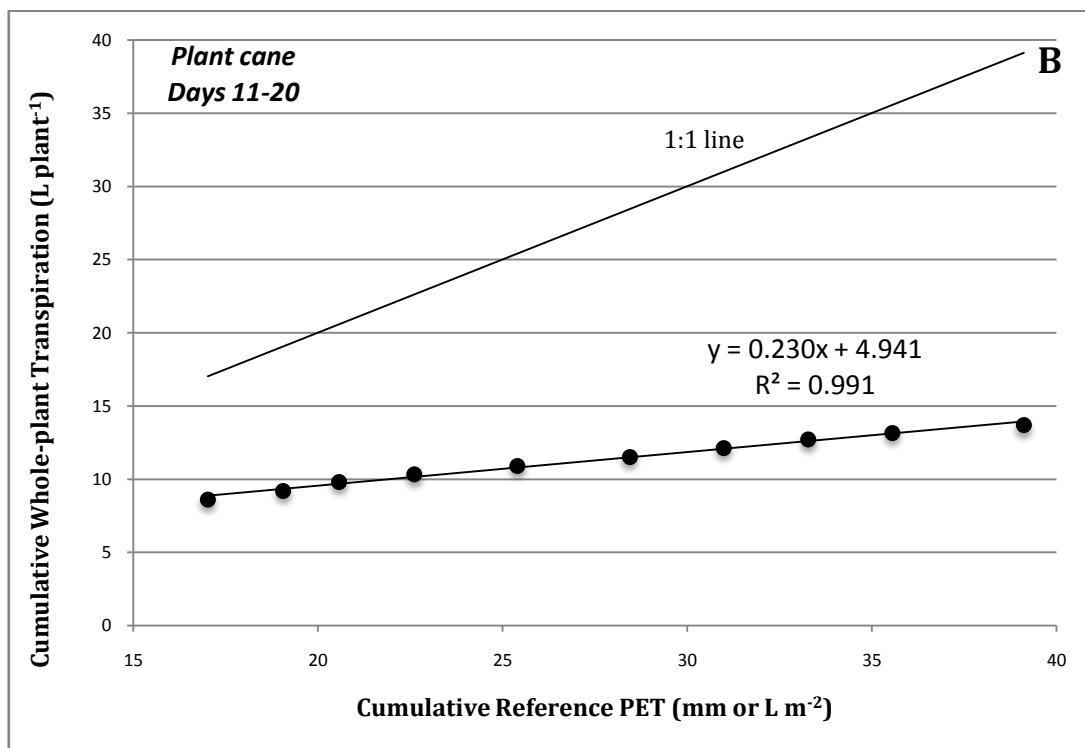
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147 **Figure 2. Progressions of the daily whole-plant transpiration of the three genotypes**
 148 **growing under a water-deficient regime during the initial plant cane phase of the**
 149 **study.**

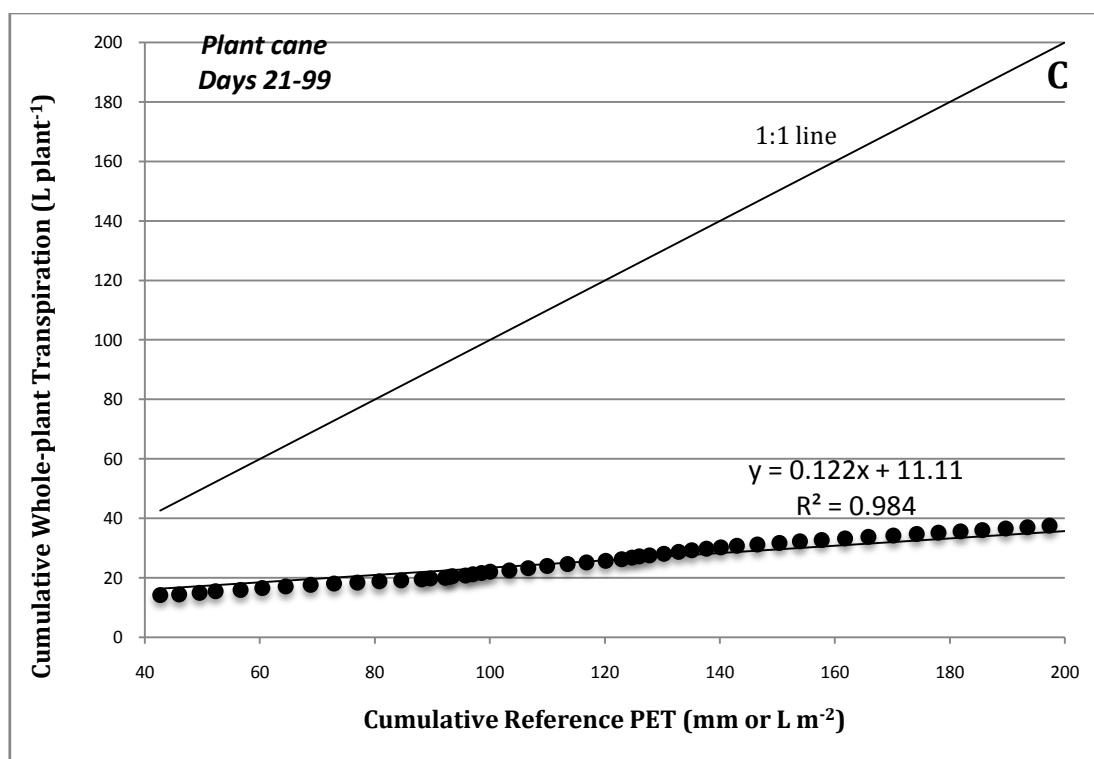
150 During the initial five days of phase 1 following the start of water deficits, the CDWPT across
 151 genotypes maintained a 1:1 relationship with CRPET (slope of the linear regression of
 152 CDWPT on CRPET was 0.9983) as plant leaf area continued to grow and leaf transpiration
 153 remained uninhibited (Fig. 3A). During the following five days (days 6-10), CDWPT averaged
 154 37% of CRPET (slope of linear regression was 0.3675), which resulted from decreasing
 155 DWPT likely due mainly to the inhibition of leaf area growth (Fig. 3A). As the restriction in
 156 daily irrigation led to further reductions in soil water content, CDWPT continued to decline
 157 averaging 23% of CRPET during the following 10 days (Fig. 3B). During the following 79
 158 days, CDWPT averaged 12% of CRPET (slope equal to 0.1229), which resulted in CDWPT
 159 being 19% of CRPET on day 99 (Fig. 3C). These declines in CDWPT from day 11 to day 99
 160 resulted likely through the combined effects of stomatal closure and leaf growth inhibition
 161 [10,11]. The almost flat progression of DWPT after day 55 (July 6, 2015) observed in Fig. 2
 162 appears to indicate that leaf area growth was fully inhibited from that point in time.



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165

166 **Figure 3. Linear regression of cumulative whole-plant transpiration on cumulative**
 167 **reference potential evapotranspiration calculated for distinct periods within the plant**
 168 **cane phase of the study. Cumulative whole-plant transpiration values were calculated**
 169 **with daily whole-plant transpiration averaged across the three studied genotypes.**

170 There were no differences in above-ground dry biomass production or its partitioning among
 171 genotypes during the plant cane first phase of the study under a water-deficient regime
 172 (Table 1). Total above-ground dry biomass averaged 437.6 g per pot across genotypes,
 173 comprised of 140.3 g per pot of dry leaf blades and 297.3 g per pot of dry stems including
 174 leaf sheaths.

175 There were differences among genotypes, however, in their tillering characteristics (Table 1).
 176 The number of tillers produced by the sugarcane genotype TCP94-5753 was about 42%
 177 lower than those produced by the two energycane genotypes TUS56 and TUS59. The ability
 178 of energy cane to produce a larger number of stalks (tillers) was reported before [1].
 179 Genotype TUS56 produced a larger length of tillers than the other two genotypes; 1.29 times
 180 more than TUS59 and 2.62 times more than TCP94-5753. These differences led to TCP94-
 181 5753 exhibiting a much higher specific stem length than the energycane genotypes; 2.5
 182 times higher than that of TUS56 and 1.87 times higher than that of TUS59.

183 There were no differences in water economy among genotypes after exposure to water
 184 deficits during phase 1 (Table 1), as represented by CDWPT, transpiration per unit dry leaf
 185 mass, and a nominal water use efficiency. Cumulative whole-plant transpiration during this
 186 plant cane phase averaged 61.5 L per pot across genotypes. Transpiration per unit leaf
 187 mass, averaged 0.381 L g⁻¹ across genotypes. The nominal water use efficiency averaged
 188 7.1 g L⁻¹ across genotypes.

189 **Table 1. Summaries of statistical analyses of state variables related to above-ground**
 190 **biomass partitioning, tillering characteristics, and water economy of two energy cane**
 191 **genotypes and one sugarcane genotype growing during the initial plant cane phase of**
 192 **the study under a water-deficient regime.**

<i>Growth phase: plant cane</i>			
Above-Ground Dry Biomass Partitioning			
	Leaf blades	Stems (including leaf sheaths)	Total Above- Ground Biomass
Genotype	(g per pot)	(g per pot)	(g per pot)
TUS56	138.1 a	293.6 a	431.7 a
TUS59	153.3 a	307.5 a	460.7 a
TCP94-5753	129.6 a	290.7 a	420.3 a
LSD 0.05	25.7	95.9	93.9
Tillering Characteristics			
	Number of tillers	Total length of tillers	Specific stem length
Genotype	(per pot)	(m per pot)	(g m⁻¹)
TUS56	11.6 a	0.76 a	39.0 b
TUS59	12.4 a	0.59 b	52.1 b
TCP94-5753	5.0 b	0.29 c	97.4 a
LSD 0.05	1.9	0.14	17.1
Water Economy			
	Cumulative Water Use	Cumulative Water Use per Leaf Mass	Nominal Water Use Efficiency
Genotype	(g per pot)	(L g⁻¹)	(g L⁻¹)
TUS56	63.9 a	0.467 a	6.8 a
TUS59	59.9 a	0.395 a	7.7 a
TCP94-5753	60.6 a	0.472 a	6.9 a
LSD 0.05	4.7	0.0938	1.6

193 Means followed by a different letter are significantly different at .05 level

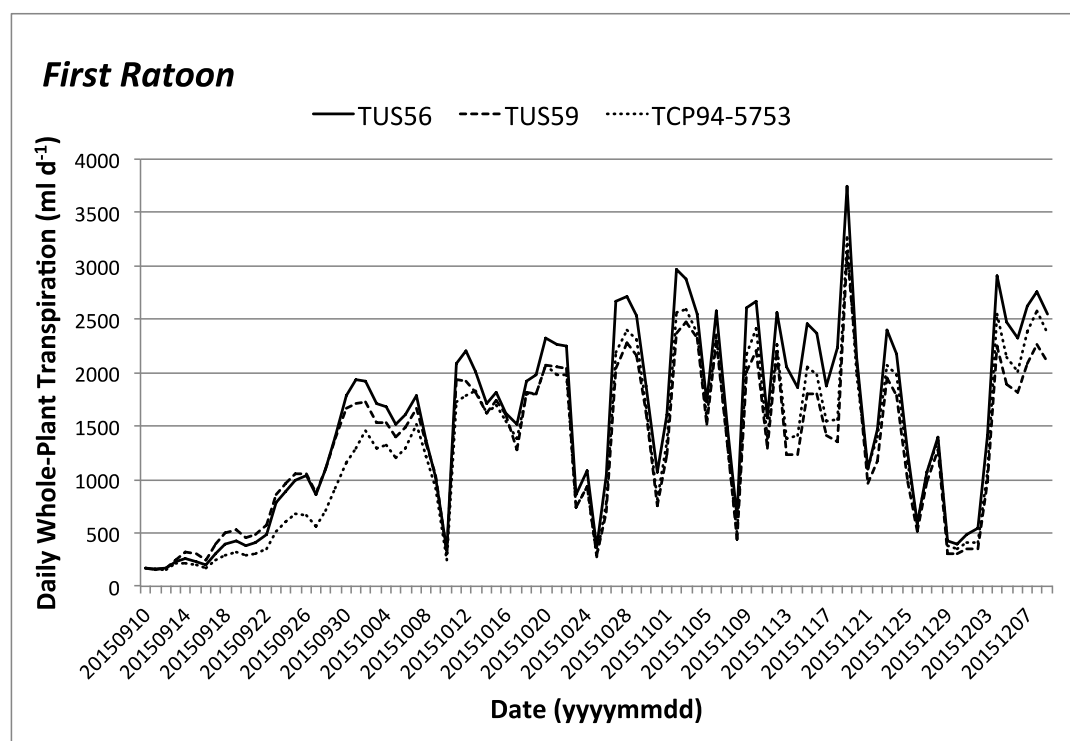
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195 3.2 Phase 2 of study: First ratoon cane under well-watered conditions

196 Day-to-day variation of daily whole-plant transpiration observed during the first ratoon cane
 197 phase under well-watered conditions (Fig. 4) resulted primarily from: a) normal day-to-day
 198 variation in weather conditions and b) progressive variations in leaf area per plant, including
 199 production of new leaves and leaf expansive growth. Progression of daily RPET during this
 200 second phase of the study, which extended for 91 d and occurred mostly during the fall

season (Fig. 1) was characterized by the normal day-to-day variation and an overall increasing trend during the first 24 d, followed by an overall declining trend accentuated from day 76 to day 85. The progressions of daily whole-plant transpiration for the three genotypes studied showed generally higher values for the energy cane TUS56 (Fig. 4). Since plants were grown under a well-watered regime, daily whole-plant transpiration values were much higher than those observed during the previous plant cane phase grown under a water-deficient regime during the summer season.

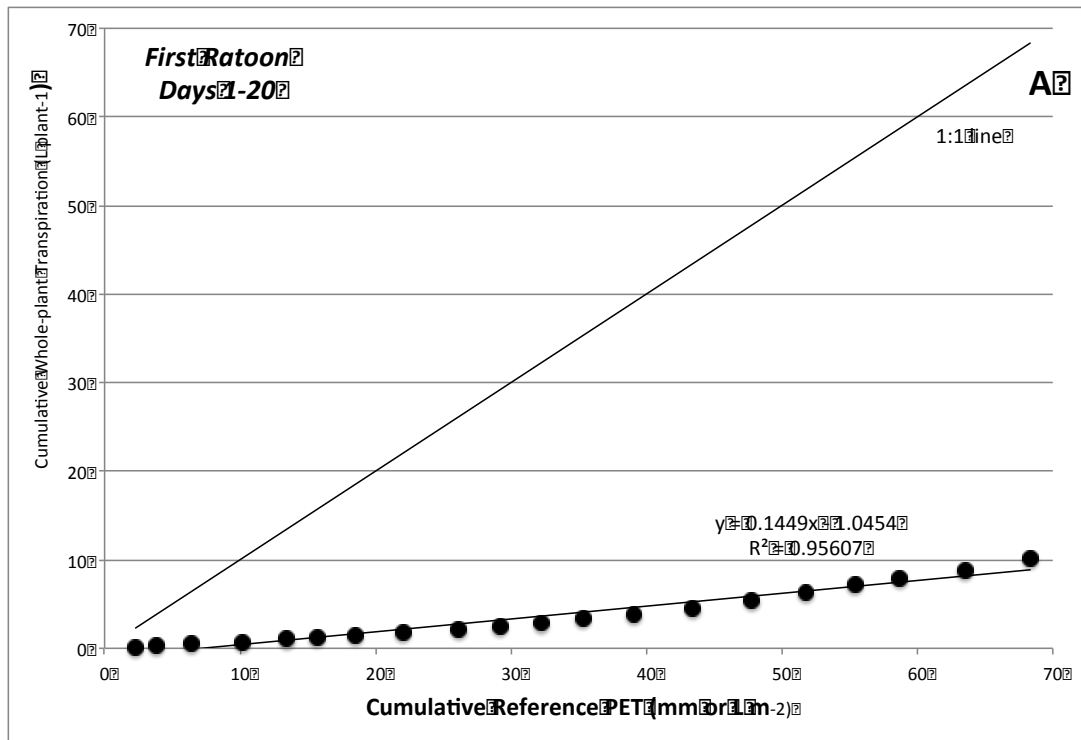
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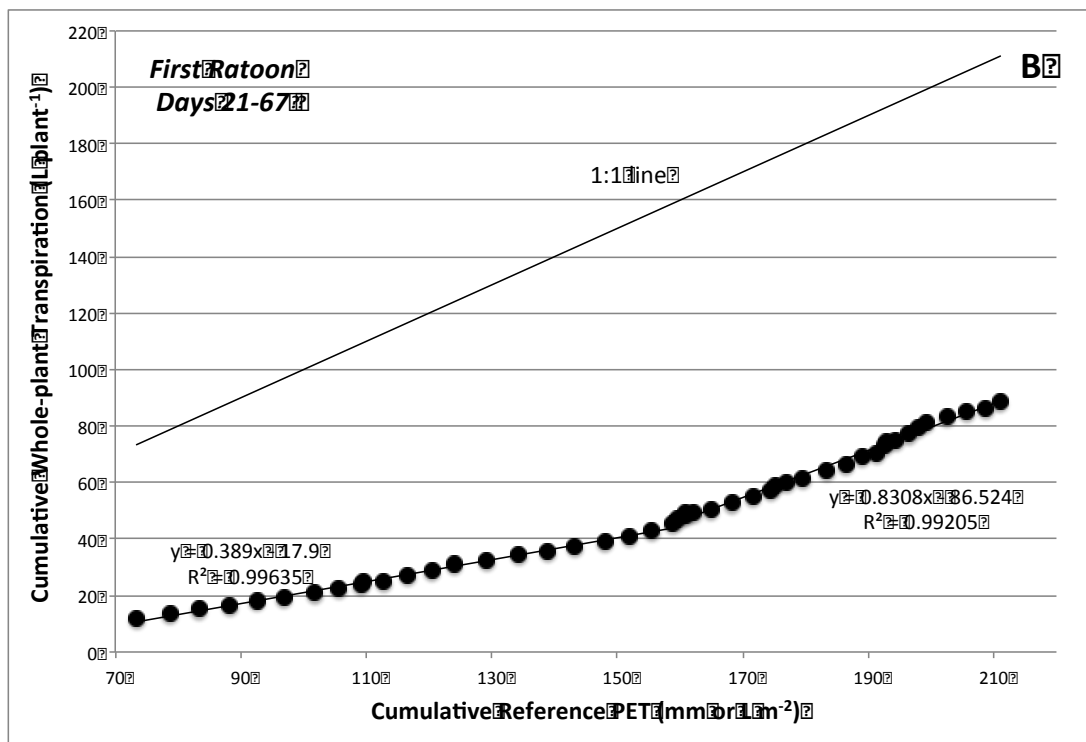
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210 **Figure 4. Progressions of the daily whole-plant transpiration of the three genotypes**
 211 **growing under a well-watered regime during the first ratoon cane phase of the study.**

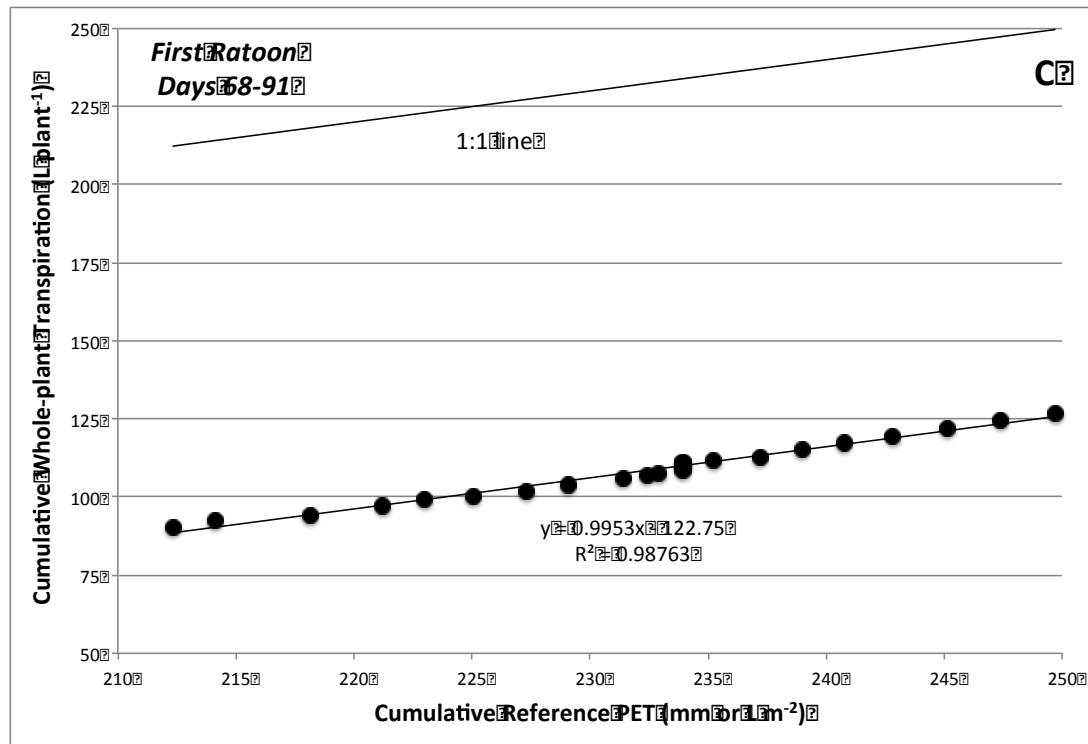
212 During the initial 20 days of the well-watered first ratoon phase, which followed above-
 213 ground harvest of the plant cane phase, the CDWPT across genotypes remained at about
 214 14% of CRPET (slope of the linear regression of CDWPT on CRPET was 0.1449, as shown
 215 in Fig. 5A), as above-ground plant growth slowly began developing leaves. During the
 216 following 46 days (days 21-67) as plants entered a rapid growth rate and plant leafiness
 217 increased, CDWPT averaged 39% of CRPET during the first half of this period and 83% of
 218 CRPET during the second half (slopes of linear regression were 0.389 and 0.8308,
 219 respectively, as shown in Fig. 5B). From day 68 to 91, the average CDWPT paralleled the
 220 average CRPET (slope of linear regression was 0.9953), as plant foliage continued to
 221 increase (Fig. 5C).



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225 **Figure 5. Linear regression of cumulative whole-plant transpiration on cumulative**
 226 **reference potential evapotranspiration calculated for distinct periods within the first**
 227 **ratoon cane phase of the study. Cumulative whole-plant transpiration values were**
 228 **calculated with daily whole-plant transpiration averaged across the three studied**
 229 **genotypes.**

230 There were no differences in above-ground dry biomass production or stems dry biomass
 231 (including leaf sheaths) among genotypes during the first ratoon cane phase of the study
 232 under a well-watered regime (Table 2). Total above-ground dry biomass and stems dry
 233 biomass averaged, respectively, 886 and 552.9 g per pot across genotypes. There were
 234 differences among genotypes, however, in leaf blades dry biomass. TUS56 produced 15 and
 235 10% more leaf blades biomass than TUS59 and TCP94-5753, respectively.

236 There were differences among genotypes in their tillering characteristics at the end of the
 237 well-watered first ratoon cane phase (Table 2). The energy cane genotypes TUS56 and
 238 TUS59 produced 2.32 and 1.83 times more tillers than the sugarcane genotype TCP94-
 239 5753, respectively, while TUS56 produced 27% more tillers than TUS59. As was reported
 240 earlier [1], and as results showed during the previous plant cane phase under a water-
 241 deficient regime, the energy cane genotypes growing under a well-watered regime during
 242 this first ratoon cane phase also exhibited the ability to produce a larger number of stalks
 243 (tillers) than the sugarcane genotype. The high tillering ability of energy cane genotypes has
 244 been linked to their rhizomatous rooting system [18]. Similarly, the energy cane genotypes
 245 TUS56 and TUS59 produced 2.66 and 2.14 times more length of tillers than the sugarcane
 246 genotype TCP94-5753, respectively. Genotype TUS56 produced 25% more length of tillers
 247 than TUS56. These differences led to TCP94-5753 exhibiting about 2.18 times higher
 248 specific stem length than the energy cane genotypes. There was no difference in specific
 249 stem length between the energy cane genotypes TUS56 and TUS59. These results indicate
 250 also that the tillering potential of energy cane genotypes may differ substantially.

There were differences in water economy among genotypes during in the well-watered first ratoon phase (Table 2). Cumulative whole-plant transpiration during this phase was 17% higher for TUS56 than for TUS59 and TCP94-5753, which appears to be closely related to the higher leafiness of TUS56 relative to the other genotypes. Transpiration per unit leaf mass was not different between the energy cane genotypes, but was about 6.4% higher than that of the sugarcane genotype. The nominal water use efficiency was similar for TUS59 and TCP94-5753, but 12.3% lower for TUS56, as this energy cane genotype was the most prodigal in cumulative transpiration.

Table 2. Summaries of statistical analyses of state variables related to above-ground biomass partitioning, tillering characteristics, and water economy of two energy cane genotypes and one sugarcane genotype growing during the first ratoon cane phase of the study under a well-watered regime.

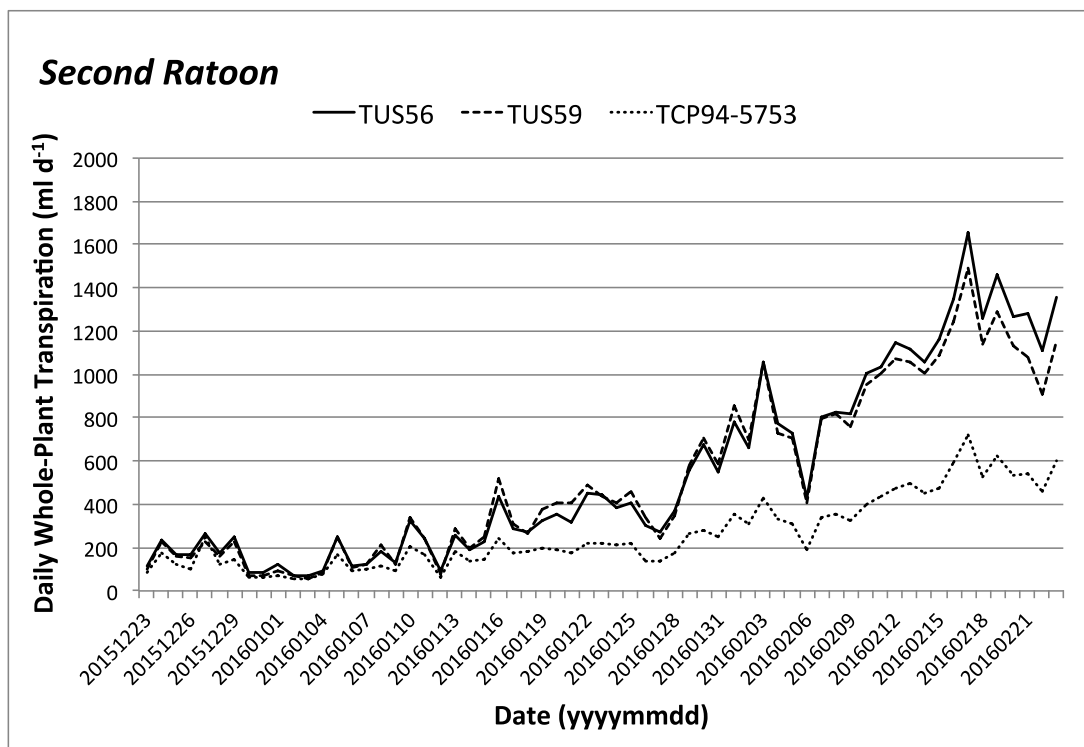
<i>Growth phase: first ratoon cane</i>			
Above-Ground Dry Biomass Components			
	Leaf blades	Stems (including leaf sheaths)	Total Above-Ground Biomass
Genotype	(g per pot)	(g per pot)	(g per pot)
TUS56	359.8 a	536.5 a	896.3 a
TUS59	313.0 b	594.0 a	907.0 a
TCP94-5753	326.7 b	528.1 a	854.7 a
LSD 0.05	20.4	76.0	85.5
Tillering Characteristics			
	Number of tillers	Total length of tillers	Specific stem length
Genotype	(per pot)	(m per pot)	(g m ⁻¹)
TUS56	46.0 a	3.30 a	16.3 b
TUS59	36.2 b	2.65 b	22.6 b
TCP94-5753	19.8 c	1.24 c	42.4 a
LSD 0.05	8.4	0.33	6.3
Water Economy			
	Cumulative Water Use	Cumulative Water Use per Leaf Mass	Nominal Water Use Efficiency
Genotype	(g per pot)	(L g ⁻¹)	(g L ⁻¹)
TUS56	140.5 a	0.392 a	6.4 b
TUS59	120.5 b	0.385 a	7.5 a
TCP94-5753	119.4 b	0.365 b	7.1 a
LSD 0.05	4.7	0.019	0.4

Means followed by a different letter are significantly different at .05 level

264 3.3 Phase 3 of study: Second ratoon cane under well-watered conditions

265 As described for the first ratoon cane phase, the day-to-day variation of daily whole-plant
 266 transpiration observed during the second ratoon cane phase under well-watered conditions
 267 (Fig. 6) resulted primarily also from: a) normal day-to-day variation in weather conditions and
 268 b) progressive variations in leaf area per plant, including production of new leaves and leaf
 269 expansive growth. Progression of daily RPET during this third phase of the study, which
 270 extended for 63 d and occurred mostly during the winter season (Fig. 1), was characterized
 271 by a normal day-to-day variation and an overall increasing trend throughout its duration. The
 272 progressions of daily whole-plant transpiration for the three genotypes studied showed much
 273 lower values for the sugarcane genotype than both energy cane genotypes. Since
 274 atmospheric evaporative demand was low at the start of this second ratoon phase although
 275 it increased steadily throughout, daily whole-plant transpiration values were lower than those
 276 observed in the fall during the previous first ratoon cane phase.

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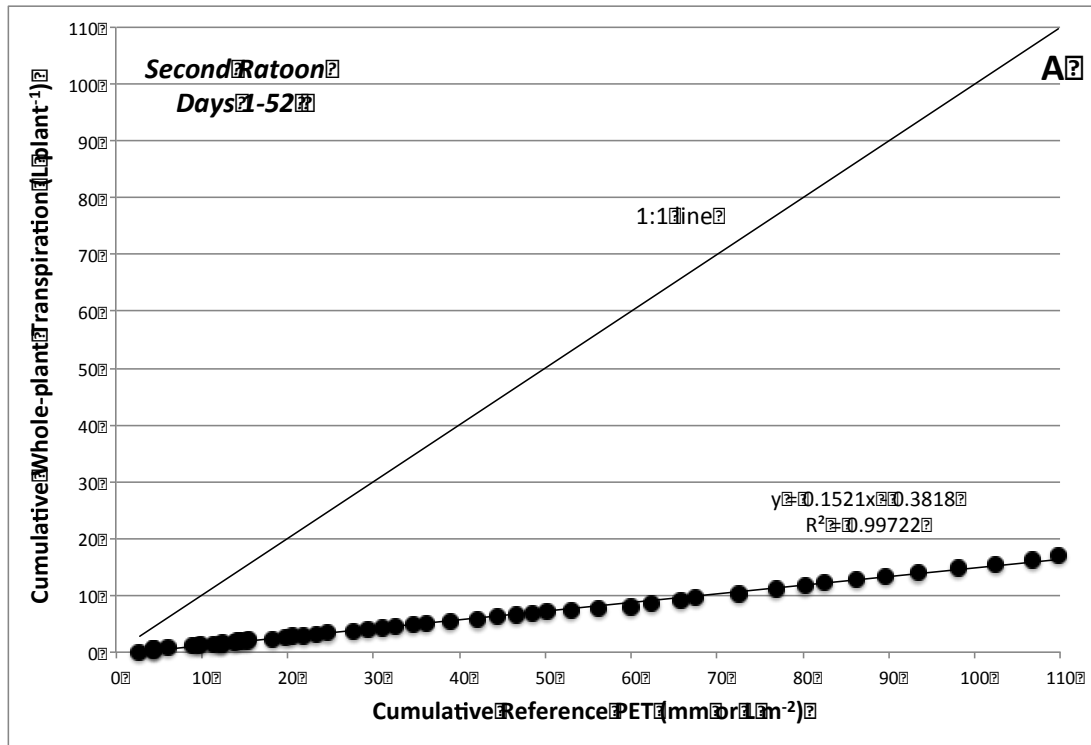
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279 **Figure 6. Progressions of the daily whole-plant transpiration of the three genotypes**
 280 **growing under a well-watered regime during the second ratoon cane phase of the**
 281 **study.**

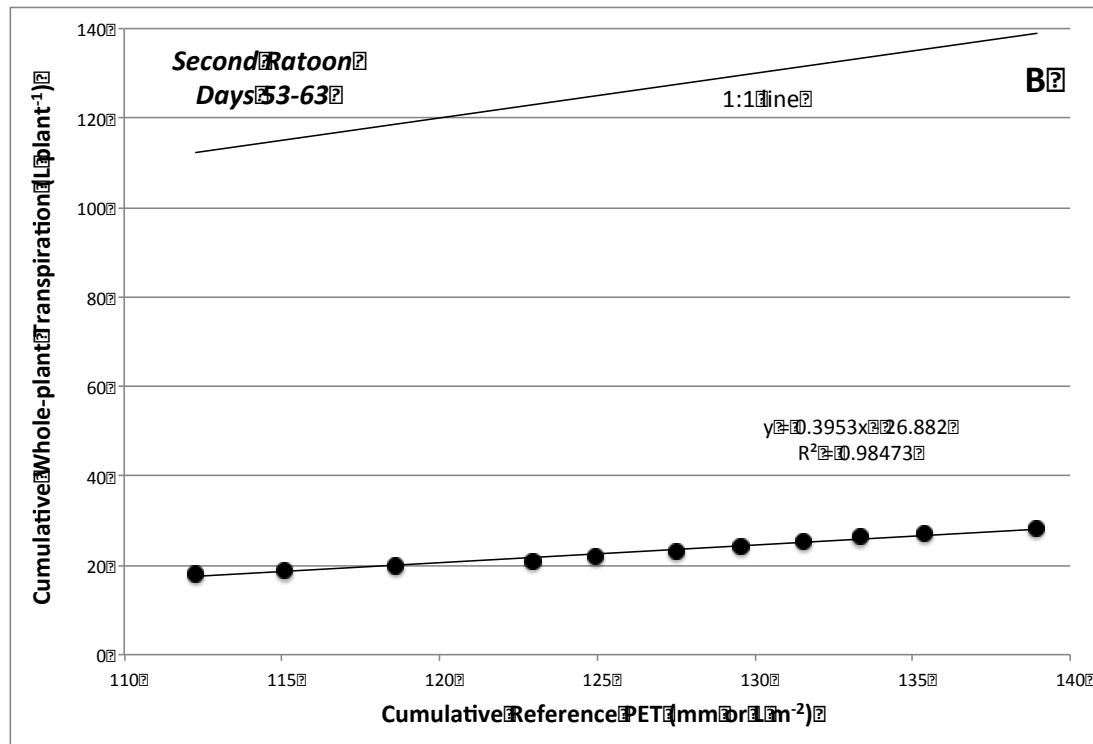
282 During the initial 52 d of the well-watered second ratoon phase, which followed the above-
 283 ground harvest of the first ratoon phase, the average CDWPT across genotypes remained at
 284 15% of CRPET (slope of linear regression of CDWPT on CRPET was 0.1521), as above-
 285 ground plant growth slowly began developing leaves (Fig. 7A). During the following 11 days
 286 (days 53-63), CDWPT averaged only 40% of CRPET (Fig. 7B), which indicates a low rate of

287 foliage development. This is particularly the case for the sugarcane genotype, which shows
 288 a much lower progression of DWPT than that of the two energycane genotypes (Fig. 6).

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292 **Figure 7. Linear regression of cumulative whole-plant transpiration on cumulative**
 293 **reference potential evapotranspiration calculated for distinct periods within the**
 294 **second ratoon cane phase of the study. Cumulative whole-plant transpiration values**
 295 **were calculated with daily whole-plant transpiration averaged across the three studied**
 296 **genotypes.**

297 There were differences in above-ground dry biomass production components among
 298 genotypes during the second ratoon cane phase of the study under a well-watered regime
 299 (Table 3). Total above-ground dry biomass, stems dry biomass, and leaf blades dry biomass
 300 were, respectively 60, 57, and 64% higher in TUS56 than in TCP94-5753, while these
 301 biomass components in TUS59 were intermediate and not significantly different from either
 302 TUS56 or TCP94-5753.

303 There were differences in water economy among genotypes during the well-watered second
 304 ratoon phase (Table 3). Cumulative whole-plant transpiration during this phase was about
 305 88% higher for the energy cane genotypes than for the sugarcane genotype. Most significant
 306 factors leading to this difference in cumulative whole-plant transpiration between the energy
 307 cane genotypes and the sugarcane genotype were a 64% higher leaf blades mass exhibited
 308 by TUS56 and a 29.5% higher transpiration per unit leaf mass exhibited by TUS59. There
 309 were no significant differences in transpiration per unit leaf mass between the two energy
 310 cane genotypes, nor between TUS56 and the sugarcane genotype TCP94-5753. The
 311 nominal water use efficiency of TCP94-5753 was about 25% higher than that of the energy
 312 cane genotypes, which resulted from the combined effect of producing an average 33% less
 313 above-ground biomass but an average 47% less cumulative transpiration than the energy
 314 cane genotypes.

Table 3. Summaries of statistical analyses of state variables related to above-ground biomass partitioning and water economy of two energy cane genotypes and one sugarcane genotype growing during the second ratoon cane phase of the study under a well-watered regime.

Growth phase: second ratoon cane			
Above-Ground Dry Biomass Components			
Genotype	Leaf blades (g per pot)	Stems (including leaf sheaths) (g per pot)	Total Above- Ground Biomass (g per pot)
TUS56	212.0 a	381.2 a	593.2 a
TUS59	177.7 ab	335.5 ab	513.1 ab
TCP94-5753	129.3 b	242.5 b	371.8 b
LSD 0.05	61.4	122.3	177.7
Water Economy			
Genotype	Cumulative Water Use (g per pot)	Cumulative Water Use per Leaf Mass (L g ⁻¹)	Nominal Water Use Efficiency (g L ⁻¹)
TUS56	35.8 a	0.170 ab	6.0 b
TUS59	32.3 a	0.180 a	5.7 b
TCP94-5753	18.1 b	0.139 b	7.3 a
LSD 0.05	6.5	0.0316	1.3

Means followed by a different letter are significantly different at .05 level

4. CONCLUSIONS

Three sequential studies made it possible to characterize and comparatively evaluate the water economy and growth performance of two energy cane genotypes (TUS56 and TUS59) and one sugarcane genotype (TCP87-3388), the first study conducted during the initial plant cane phase subjected to soil water deficits and the following two studies conducted during two subsequent ratoon cane phases under well-watered conditions.

At the end of the 99-d long initial plant cane phase, during which water stress incrementally developed from day 6 throughout day 20 and afterward stabilized to a daily whole-plant transpiration of about 12% of the potential evapotranspiration, there were no differences in above-ground dry biomass production or water economy among genotypes. However, the tillering characteristics between energy cane genotypes and the sugarcane genotype were different; the number of tillers produced by the energy cane genotypes was about 2.4 times greater than those produced by the sugarcane genotype.

334 During the 91-d long well-watered first ratoon cane phase, plants were grown under well-
335 watered conditions for 91 days, environmental conditions allowed plants to develop sufficient
336 leafiness by day 67 so that whole-plant transpiration paralleled potential evapotranspiration.
337 At the end of this first ratoon cane phase there were no differences in above-ground dry
338 biomass production or stems dry biomass (including leaf sheaths) among genotypes.
339 However, energy cane genotype TUS56 produced 15 and 10% more leaf blade dry biomass
340 than TUS59 and TCP94-5753, respectively. The energy cane genotypes TUS56 and TUS59
341 produced 2.32 and 1.83 times more tillers than the sugarcane genotype, respectively, while
342 TUS56 produced 27% more tillers than TUS59. This latter result indicates that the tillering
343 potential of energy cane genotypes may differ substantially. This higher tillering ability of
344 energy cane genotypes over the sugarcane genotype, exhibited after both the water-
345 stressed plant cane phase and this well-watered first ratoon cane phase has been linked to
346 their rhizomatous rooting system. The energy cane genotypes produced a total length of
347 tillers more than twice than the sugarcane genotype but, consequently, their specific stem
348 length was about half of that of the sugarcane genotype. The specific stem length was not
349 different between the energy cane genotypes. Cumulative whole-plant transpiration during
350 this phase was 17% higher for TUS56 than for TUS59 and TCP94-5753, which appears to
351 be closely related to the higher leafiness of TUS56 relative to the other genotypes.
352 Transpiration per unit leaf mass was not different between the energy cane genotypes, but it
353 was about 6.4% higher than that of the sugarcane genotype. The nominal water use
354 efficiency was similar for TUS59 and TCP94-5753, but 12.3% lower for TUS56, as this
355 energy cane genotype was the most prodigal in cumulative transpiration.

356 During the 63-d long well-watered second ratoon cane phase took place mostly during the
357 winter season and, consequently, plant growth occurred at a lower rate than during the first
358 ratoon cane phase due too the cooler temperatures and lower solar radiation. Because of
359 this lower plant growth rate, plant leafiness did not fully developed, which led to whole-plant
360 transpiration to be about 40% of potential evapotranspiration. Total above-ground dry
361 biomass, stems dry biomass, and leaf blades dry biomass were about 60% higher in TUS56
362 than in the sugarcane genotype, but not different from those in TUS59. Cumulative whole-
363 plant transpiration during this phase was about 88% higher for the energy cane genotypes
364 than for the sugarcane genotype. There were no differences in transpiration per unit leaf
365 mass between the two energy cane genotypes. Because comparatively the sugarcane
366 genotype produced 33% less above-ground biomass but used 57% less water than the
367 energy cane genotypes, it exhibited a 25% higher nominal water use efficiency.

368 Although harvesting the plants at an early growth stage would have compromised the build
369 up of abundant plant's stored reserves for re-growth, the better tillering ability shown by the
370 energy cane genotypes over the sugarcane genotype during the first ratoon cane phase and
371 the better above-ground biomass production of energy cane over sugarcane in the second
372 ratoon cane phase are both consistent with previous reported findings.

373

374 **COMPETING INTERESTS**

375

376 Authors have declared that no competing interests exist.

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