Canopy temperature: a predictor of sugarcane yield for irrigated and rainfed conditions

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Abstract  Our recent work with a large genetically diverse sugarcane germplasm (131 clones) grown at different commercial production regions over multiple years with varying water supply (a total of 27 crop cycles) has shown that canopy conductance ($g_c$), and a related easy-to-measure trait, canopy temperature (Tc), when integrated with canopy development, have a strong genetic correlation with crop yield irrespective of the growing condition. In order to exploit this result for variety improvement in the Sugar Research Australia breeding program, three different Tc measurement systems were assessed for their accuracy, genetic correlation of measured Tc with cane yield (tonnes cane per hectare, TCH) and trait (Tc) and heritability. The methods include manual ground-level Tc measurements taken at 3-6 month crop age, aerial screening using UAV-assisted infra-red and optical imagery and continuous real-time absolute Tc measurements using ArduCrop infra-red radiometers. Significant genetic variation for Tc among genotypes was detected with all three methods, with aerial screening and ArduCrop being more accurate and useful than manual ground-level measurements. Both UAV-aided and ArduCrop-based Tc measurements showed high heritability and high negative genetic correlation under variable moisture conditions. Results of field experiments suggest that aerial Tc measurements taken under the appropriate conditions will be an effective, rapid screening method for selecting superior, water-efficient and high-yielding clones from large breeding trials.

Key words  Sugarcane, selection, high-throughput, heritability, water stress

INTRODUCTION

Sugarcane is a high-biomass crop grown mostly under rainfed condition. Hence, commercial crops, mostly under rainfed areas often experience periods of water deficit before completing the crop cycle. Reduction in yield caused by sub-optimal water supply is a recognised productivity constraint in all crops including sugarcane (Inman-Bamber et al. 2007). Considering the economic impact caused by water deficit, many sugar industries are now investing in genetic improvement of sugarcane for water use efficiency (WUE) and water stress tolerance through conventional breeding (Hemaprabha et al. 2006; Basnayake et al. 2015).

Multi-location field studies of Australian sugarcane germplasm covering 17 different production environments showed substantial genetic variation for biomass production and sugar yield in both well-watered and water stressed conditions (Basnayake et al. 2012a). Subsequent clone characterisations showed large genetic variation, up to 2.5-fold, in transpiration efficiency (Basnayake et al. 2012b; Jackson et al. 2016) in the test germplasm, suggesting the existence of large untapped genetic potential for water productivity improvement through breeding. However, practically useful cost-effective selection trait(s) for screening large breeding populations for WUE or water stress tolerance is not available for sugarcane.

Our recent studies with sugarcane germplasm showed a strong genetic correlation between canopy conductance ($g_c$), stomatal conductance at canopy level measured at the early crop growth, and cane yield in different production regions with varying water supply (Basnayake et al. 2015). In addition, $g_c$ is a direct measure of transpirational water loss and thus has been used for assessing the genetic variation for WUE and yield in different water supply conditions (Pinter et al. 1990; Horie et al. 2006). Measurement of $g_c$ is time-consuming, however, it can be readily determined by an easy-to-measure surrogate trait, canopy temperature (Tc), which has been proposed as a selection trait for improving water productivity and yield in several crops under variable moisture conditions (Reynolds et al. 1994; Amani et al. 1996; Olivares-Villegas et al. 2007; Araus and Cairns 2014). Tc is highly sensitive to environmental variables and its dynamics, therefore, is crop-
specific. Hence, field-based cost-effective high-throughput rapid screening platforms and optimal measurement conditions are to be established (Groblinsky et al. 2015). Our work aimed to evaluate three different methods of Tc measurements and identify the most effective method for eventual use in screening large sugarcane breeding populations for TCH and WUE.

METHODS AND MATERIALS

Field experimental design and crop growth conditions

Four separate field experiments with 99, 89, 40 and 20 sugarcane genotypes, consisting of breeding lines, commercial varieties, introgression and foreign clones, were conducted at Crystal Creek, Home Hill, Dalbeg and Brandon located in north-east Queensland, Australia from 2008 to 2014. Clones for the Dalbeg (40) trial were selections from the Crystal Creek and Home Hill trials. The details of genotypes, experimental design and crop management practices of the Crystal Creek, Home Hill and Dalbeg trials were described previously (Basnayake et al. 2012a, 2015). In brief, the Crystal Creek and Brandon trials were rain-fed while in the other two locations crops were grown with varying water supply. The Brandon experiment was established in May 2013 with 20 test clones. Nine clones were selected from the Dalbeg experiment with contrasting gc and TCH, and the remaining 11 clones were advanced lines from the sugarcane breeding program. In this trial, ArduCrop infra-red radiometers (O'Shaughnessy et al. 2011) were permanently installed in the plots of 10 clones with contrasting gc.

In all four sites plot size was 10 m x 4 rows, with 1.52 m inter-row spacing, and the trial design was a randomized block with 2 or 3 replications. Best management practices recommended for each location were adapted. Mature crops were harvested by a commercial cane harvester in June or July each year at an approximate age of 12 months. The two middle rows of each plot were harvested and weighed to determine TCH. The ratoon 1 (1R) crops in Home Hill, Crystal Creek (2008), Dalbeg (2011) and Brandon (2014) were used to evaluate the genetic variation for Tc among test genotypes. Weather data was recorded using automated weather stations (Campbell Scientific Australia Ltd.) located within 200-700 m from the experimental sites. Daily rainfall, radiation, relative humidity (RH), temperature and vapour pressure deficit (VPD) were recorded during the experimentation.

Canopy temperature measurements

Three different Tc measurement systems were investigated for their accuracy, suitability for field-grown sugarcane crops and trait (Tc) heritability.

Method 1). Proximal, ground-based system using hand-held infra-red thermometer (IRT, Micron, Model AG 42, California)

Micron IRT was used to determine Tc in 3-6 month old crop at Crystal Creek (rainfed) and Home Hill (irrigated and rainfed) during October to December 2008. Tc measurements were made from 09:00 to 15:00 on relatively clear sky days. On each plot, 3-5 spot measurements covering the middle 8 m of the two inner rows were taken 1 m away from the crop with the instrument pointing straight to the centre of canopy at an angle of 45° to the vertical line. The data was automatically stored in a logger.

Method 2). Measurements using Pheno-Copter (unmanned aerial vehicle, UAV) fitted with thermal cameras and imaging equipment

Thermal images were obtained remotely on a very clear day in November 2011 using an UAV with autonomous flight control. A five-month-old 1R crop with 3 water treatments (irrigated, half-irrigated, rainfed) and 40 genotypes at Dalbeg was used for UAV-based study. The way-points for the mission were identified and the flight path was arranged to cover 12 rows (3 plot width) in one direction. The details of the Pheno-Copter operation were described by Chapman et al. (2014). The infra-red thermal camera has not been calibrated for sugarcane Tc. Hence, during the flight, hand-held IRT was used to take random spot measurements for comparison. The average intensity of heat absorption (AIA; the measured infra-red parameter for Tc) for each plot was used for Tc analysis. The AIA data generated with several flights between 10:00 to 13:00 was used to analyse Tc variation among treatments and test clones.

Method 3). Measurements using ArduCrop infra-red radiometers

The Tc variation was determined using ArduCrop positioned 1 m above the canopy level at an angle of 45° to the vertical line. These instruments were installed in 30 plots (3 replicates x 10 genotypes) in a 1R crop grown under rainfed conditions.
at Brandon. The data was recorded at 1 minute interval for 56 days from 2 May 2014. Hourly Tc was calculated by taking the average Tc of 60 observations. The average across 56 day hourly temperatures (00:00-23:00) of 30 plots was used to analyse the Tc variation among clones at different times of the day.

**Statistical analysis**

Analysis of variance (ANOVA) was initially performed for each time of Tc measurements to determine the genetic variances and heritability. For each measurement, genetic and error variances were estimated and broad sense heritability ($h^2_b$) was calculated on the basis of genotype means. Clone x water treatment interaction variance component was estimated when two factors were used to estimate the heritability. The genetic correlation between Tc and TCH was also determined.

**RESULTS**

**Weather conditions at Crystal Creek, Home Hill and Brandon**

Daily radiation fluctuation was high, and the average radiation during the measurement period was around 25 MJm$^{-2}$day$^{-1}$ (Figure 1). Maximum temperature ranged from about 25°C in winter to 35°C in summer, and VPD reached approximately 1.7, 2.1 and 3.0 kPa, at Crystal Creek, Home Hill and Brandon sites, respectively. The VPD fluctuation was high in Home Hill and Crystal Creek in 2008 compared to Brandon in 2014 (Figure 1).

![Figure 1](image_url)  
*Fig. 1.* Mean daily maximum temperature (°C; continuous line), radiation (MJm$^{-2}$day$^{-1}$; dotted line) and VPD (kPa; grey bars) during the experiment period in 2008 at Crystal Creek and Home Hill (Micron IRT), and in 2014 at Brandon (ArduCrop).

**Proximal measurement of canopy temperature (manual with IRT) (Method 1)**

At Crystal Creek, large fluctuations in radiation, maximum temperature and VPD occurred during 12-month period reported here (Fig. 1). However, during Tc measurement period, weather remained relatively stable. A significant genetic variation for Tc among clones was recorded for 5 out of 6 measurement times (Table 1). The Tc measurements on 6 November was taken under cloudy and high humid conditions prior to a rain event. The heritability varied from 0.34±0.18 to 0.64±0.29, and the maximum genetic correlation for Tc and TCH was -0.44 on 16 December 2008.

Sudden changes in wind speed with changes in humidity and air temperature occurred during the measurement days in summer at Home Hill experiment (Fig. 1) causing considerable Tc fluctuation. As a result, the proximal Tc measurements at Home Hill during the day (08:00-15:00) had relatively small clone variation. Significant clone variations were observed...
only in 2 occasions out of 11 measurements (Table 1). Consequently, the estimated broad sense heritability of these measurements was low. However, when the environment conditions were relatively stable during the day on 28 November, the genetic variation and estimated heritability were moderate and significant in both rainfed (0.42±0.19) and irrigated (0.32±0.11) conditions (Table 1). The genetic correlations (Tc and TCH) for these 2 days were -0.42 and -0.34, respectively.

Table 1. Mean Tc, variance ratio, probability level for significance and coefficient of variation (CV) of ANOVA and estimated broad sense heritability for Tc measurements using IRT in different days at Crystal Creek and Home Hill under rainfed and irrigated conditions in 2008.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatments</th>
<th>Mean Tc (°C)</th>
<th>Variance ratio</th>
<th>Probability</th>
<th>CV</th>
<th>Heritability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-Oct</td>
<td>Rainfed</td>
<td>28.36</td>
<td>1.49</td>
<td>0.03</td>
<td>4.31</td>
<td>0.35</td>
</tr>
<tr>
<td>28-Oct</td>
<td>Rainfed</td>
<td>30.36</td>
<td>2.11</td>
<td>&lt;0.001</td>
<td>1.28</td>
<td>0.54</td>
</tr>
<tr>
<td>17-Nov</td>
<td>Rainfed</td>
<td>33.57</td>
<td>1.92</td>
<td>&lt;0.001</td>
<td>6.06</td>
<td>0.49</td>
</tr>
<tr>
<td>5-Dec</td>
<td>Rainfed</td>
<td>29.55</td>
<td>1.81</td>
<td>0.00</td>
<td>3.12</td>
<td>0.42</td>
</tr>
<tr>
<td>16-Dec</td>
<td>Rainfed</td>
<td>30.61</td>
<td>2.74</td>
<td>&lt;0.001</td>
<td>3.60</td>
<td>0.64</td>
</tr>
<tr>
<td>Home Hill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28-Nov</td>
<td>Rainfed</td>
<td>31.09</td>
<td>1.74</td>
<td>0.01</td>
<td>3.10</td>
<td>0.43</td>
</tr>
<tr>
<td>28-Nov</td>
<td>Irrigated</td>
<td>27.35</td>
<td>1.47</td>
<td>0.03</td>
<td>4.10</td>
<td>0.32</td>
</tr>
</tbody>
</table>

UAV-aided (Pheno-Copter) canopy temperature measurement (Method 2)

Weather conditions

The air temperature, RH and VPD variation during flights in the Dalbeg trial are shown in Figure 2. The air temperature varied from 24°C to 33°C during 08:00 to 15:00. In contrast, relative humidity dropped sharply from 80% in the morning to 31% at 14:00. Subsequently, the VPD changed from 0.88 to 3.5 kPa during that period. The light intensity was fairly stable with 2000 mmolm⁻²s⁻¹ during measurement time.

Fig. 2. Temperature (°C), humidity (RH) and VPD measured at 15-minute intervals (08:00-15:00) on the day of aerial (UAV) measurements (10:00-12:00).
UAV-aided canopy temperature measurement

At the time of measurements, the canopy cover was about 30 and 50% in rainfed and irrigated treatments, respectively, and it had some impact on Tc estimation. Hence, the Tc (AIA) was derived after masking the heat emission from the open soil and dead leaves.

The estimated AIA, the measured infra-red parameter for Tc, has been processed for each water treatment and statistically analysed (Table 2). There were three flight scans between 10:00 and 12:00, and more stable screening data was identified based on the coefficient of variation for each water treatment.

The statistical analysis for individual water treatment showed significant Tc differences among clones (Table 2). Combined analysis with three water treatments showed a significant clone x treatment interaction. Heritability estimates were moderate to high (0.49, 0.56, respectively) in the rainfed and half-irrigated treatments, and low in the irrigated treatment (0.39). Calibration of IR camera would increase the precision of the estimated Tc. The heritability estimates across three water treatments was 0.58. The genetic correlation between Tc and TCH for rainfed condition was -0.34, while the irrigated and half-irrigated were -0.69 and -0.86, respectively.

Table 2. The variance ratio, probability level for significance, coefficient of variation (CV) of ANOVA and heritability estimates of canopy temperature (Tc) for three water treatments separately and combined, in the Dalbeg trial.

<table>
<thead>
<tr>
<th>Treatments/Factors</th>
<th>Variance Ratio</th>
<th>Probability</th>
<th>CV</th>
<th>Heritability</th>
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<tr>
<td>Irrigated</td>
<td>1.37</td>
<td>0.05</td>
<td>0.44</td>
<td>0.39</td>
</tr>
<tr>
<td>Rainfed</td>
<td>1.27</td>
<td>0.04</td>
<td>1.80</td>
<td>0.49</td>
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<tr>
<td>Half-irrigated</td>
<td>2.79</td>
<td>&lt;0.001</td>
<td>1.20</td>
<td>0.56</td>
</tr>
<tr>
<td>Clone (C)</td>
<td>1.67</td>
<td>0.009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3.59</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C x T</td>
<td>1.67</td>
<td>&lt;0.001</td>
<td>1.54</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Canopy temperature measurement using ArduCrop (Method 3)

Daily temperature and radiation during the measurement period are presented in Figure 3. Significant variation for Tc among clones was recorded in the morning. Among the day time records, 08:00-10:00 showed the maximum genetic variation for Tc among clones with high heritability (Table 3), and the highest genetic correlation (-0.87). Maximum heritability was obtained between 08:00-09:00, suggesting that the best observation period would be in the morning.

Fig. 3. Daily temperature, radiation and rainfall during the canopy temperature measurements at Brandon trial using ArduCrop.
**DISCUSSION**

An important finding from this study is the establishment of genetic variation for Tc in the test populations across different production conditions by the three different methodologies used. This is significant in that Tc is a well-established surrogate trait for stomatal (and canopy) conductance (Amani et al. 1996), which is strongly correlated with yield in several crops including sugarcane (Rebetzki et al. 2013; Basnayake et al. 2015). Thus, Tc could be used as a potential selection trait for yield in sugarcane. The range of Tc variation (2-5°C) observed across different methods in these experiments is comparable with the variation reported previously by Khera and Sandhu (1986) in sugarcane, which provides further confidence in the methodologies used here.

Hand-held IRTs have been widely used to measure Tc in field experiments in many crops (Idso et al. 1981; Khera and Sandhu 1986; Blum et al. 1989; Amani et al. 1996). These proximal Tc measurements are lengthy and labour-intensive, and are heavily influenced by the variation in VPD and radiation (Idso et al. 1977). Our study clearly suggests that proximal Tc measurements can be used for clone characterisation when the environment is stable. However, the estimated error variation was large and the heritability was moderate in all proximal measurements at Crystal Creek and Home Hill indicating the inherent limitations of this system for routine use in breeding programs. A major deficiency of hand-held IRTs is the relatively low throughput, rendering it unsuitable for screening large populations.

The UAV-assisted measurements of Tc and various agronomic traits were successful in many crops (Leinonen and Jones 2004; Anthony et al. 2014; Chapman et al. 2014). This is largely because the crop aerial imagery is advancing rapidly with the development of new hardware systems and software programs allowing fast screening of large populations reducing the influence of changing environment (Anthony et al. 2014). In our study, the relative value of Tc (AIA) was estimated from the UAV data, but high resolution cameras and improved algorithms would allow more accurate Tc determination by eliminating interfering signals from soil and leaf debris (Canty 2014).

The real-time Tc measurements using ArduCrops were useful to understand the dynamic process of whole-canopy temperature regulation during the day. This revealed a significant difference in thermal regulation among sugarcane clones under the same atmospheric conditions in the field. In spite of the relatively insignificant variation in soil moisture extraction among test clones during the observation period (data not shown), we found a highly significant variation in Tc in the early hours of the day. A similar pattern has been reported in wheat (Balota et al. 2007). The results suggested that a narrow window of 2 hours between 08:00 and 10:00 would be the best period for Tc measurements in sugarcane as the heritability of measurements decreased considerably after 10:00.

Information obtained from our experiments has laid the important groundwork to establish the optimal Tc measurement methodology in sugarcane. While ground measurements would be desirable under certain conditions for detailed germplasm characterisation, automated field phenomics systems such as UAVs would provide a better opportunity to exploit Tc and other similar functional trait-based selection programs in sugarcane.

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**Table 3.** Results of the ANOVA, mean Tc, genetic and environmental variances and heritability of Tc made at hourly interval during the entire period of measurements (days).

<table>
<thead>
<tr>
<th>Time of the day (h)</th>
<th>Number of days</th>
<th>Mean Tc (°C)</th>
<th>Variance ratio</th>
<th>Probability</th>
<th>CV</th>
<th>Genetic variance</th>
<th>Environmental variance</th>
<th>Heritability</th>
</tr>
</thead>
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<tr>
<td>07:00</td>
<td>56</td>
<td>17.94</td>
<td>1.35</td>
<td>0.30</td>
<td>1.67</td>
<td>0.01</td>
<td>0.08</td>
<td>0.26</td>
</tr>
<tr>
<td>08:00</td>
<td>53</td>
<td>21.37</td>
<td>2.34</td>
<td>0.05</td>
<td>1.61</td>
<td>0.06</td>
<td>0.12</td>
<td>0.59</td>
</tr>
<tr>
<td>09:00</td>
<td>52</td>
<td>24.58</td>
<td>4.25</td>
<td>0.02</td>
<td>1.43</td>
<td>0.19</td>
<td>0.08</td>
<td>0.88</td>
</tr>
<tr>
<td>10:00</td>
<td>56</td>
<td>26.61</td>
<td>2.43</td>
<td>0.05</td>
<td>1.35</td>
<td>0.06</td>
<td>0.12</td>
<td>0.59</td>
</tr>
<tr>
<td>11:00</td>
<td>54</td>
<td>27.68</td>
<td>1.58</td>
<td>0.22</td>
<td>1.62</td>
<td>0.04</td>
<td>0.19</td>
<td>0.36</td>
</tr>
<tr>
<td>12:00</td>
<td>56</td>
<td>27.90</td>
<td>1.21</td>
<td>0.36</td>
<td>1.72</td>
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<td>0.22</td>
<td>0.18</td>
</tr>
<tr>
<td>13:00</td>
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<td>1.84</td>
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<td>53</td>
<td>27.64</td>
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<td>1.51</td>
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<td>0.22</td>
<td>0.18</td>
</tr>
<tr>
<td>15:00</td>
<td>54</td>
<td>26.58</td>
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<td>0.12</td>
<td>1.15</td>
<td>0.03</td>
<td>0.09</td>
<td>0.51</td>
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<tr>
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<td>1.16</td>
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</tr>
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<td>22.69</td>
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<td>0.07</td>
<td>0.91</td>
<td>0.02</td>
<td>0.05</td>
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</tr>
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ACKNOWLEDGEMENTS

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REFERENCES


La température de la canopée: un indicateur de rendement de la canne à sucre irriguée et pluviale

Résumé. Nos récents travaux avec un grand éventail de matériel génétique de la canne à sucre (131 clones), cultivé dans différentes régions de production commerciale sur plusieurs années (27 cycles de cultures) avec différents approvisionnements en eau, ont démontré que la conductance de la canopée (g_c) et un trait connexe plus facile à mesurer - la température de la canopée (T_c) - montrent une grande corrélation génétique avec le rendement, lorsqu'ils sont intégrés avec le développement de la culture, indépendamment des conditions de croissance. Afin d'exploiter ce résultat dans le programme de sélection et d'amélioration variétale du Sugar Research Australia, trois différents systèmes de mesure de T_c ont été évalués pour leur précision, la corrélation T_c mesurée et le rendement en canne (tonnes par hectare, TCH) et le trait (T_c) et l'héritabilité. Les méthodes de mesure de T_c comprenaient une mesure manuelle in situ à l'âge de 3-6 mois, une mesure aérienne par l'imagerie infrarouge et optique assistée par UAV, et finalement des mesures continues des valeurs absolues de T_c en temps réel à l'aide de radiomètres à infrarouges ArduCrop. Des variations génétiques significatives de T_c ont été détectées parmi les génotypes avec les trois méthodes. Les mesures de T_c avec l'imagerie assistée par UAV et ArduCrop étaient plus précises et plus utiles que celles effectuées manuellement in situ et ont montré une forte héritabilité et une grande corrélation génétique négative dans des conditions d'humidité variables. Les résultats de ces mesures sur le terrain suggèrent que les mesures aériennes de T_c prises dans les conditions appropriées offrent une méthode de dépistage efficace et rapide pour la sélection des clones de qualité supérieure, résistants au stress hydrique et à haut rendement à partir de grands essais de sélections variétales.

Mots-clés: Canne à sucre, la sélection, essais à haut débit, héritabilité, stress hydrique

Temperature de dosel: un pronosticador del rendimiento en caña de azúcar en condiciones de regadío y secano

Resumen. Nuestros trabajos recientes con un germoplasma altamente diverso genéticamente (131 clones), cosechados en diferentes regiones de producción comercial por varios años, con un suministro variable de agua (con un total de 27 ciclos de cosecha) han mostrado que la conductancia del dosel (g_c) y un indicador fácil de medir la temperatura de dosel (T_c) cuando se integra con el desarrollo del dosel, tiene una fuerte correlación genética con el rendimiento de cosecha independientemente de las condiciones de cultivo. Con el propósito de explotar este resultado en el desarrollo de variedades en el programa de mejoramiento del "Sugar Resarch Australia", se evaluaron tres (3) métodos diferentes de medición de Tc para conocer su precisión, la correlación genética de los valores de Tc medidos con el rendimiento cañero (toneladas de caña por hectárea, TCH), y el indicador Tc y la capacidad de heredar esta condición. Los métodos incluyen las mediciones manuales de Tc a nivel del suelo tomadas a las edad de 3-6 meses del cultivo, tamizado aéreo empleando imaginología infrarroja y óptica UAV-asistida y mediciones continuas en tiempo real de Tc, empleando radiómetros infrarrojos ArduCrop. Se detectaron significativas variaciones genéticas para los Tc entre los genotipos por todos los tres métodos, resultando el tamizado aéreo y el ArduCrop los más precisos y útiles que la medición manual a nivel del suelo. Ambas las mediciones de Tc con auxilio -UAV y la basada en ArduCrop, mostraron una alta capacidad de heredar y una alta correlación genética negativa bajo condiciones de humedad variables. Los resultados de los experimentos de campo sugieren que las mediciones aéreas tomadas bajo condiciones apropiadas serán un rápido método de tamizado para la selección de clones con alta eficiencia al agua y altos rendimientos en grandes experimentos de cruzamiento.

Palabras clave: Caña de azúcar, selección, alta capacidad de heredar, estrés hídrico