Final report - SRDC project: BSS304: Cane grower implemented drying-off irrigation scheduling on the tablelands

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CANE GROWER IMPLEMENTED DRYING-OFF IRRIGATION SCHEDULING ON THE TABLELANDS

by

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SUMMARY

Detrimental effects attributed to the drying-off of a sugarcane crop include biomass reduction, crop fermentation and reduced ratooning, all of which can result in substantial economic losses. Methods used to measure crop development during the drying-off process have been largely laboratory based, where the grower is required to send cane samples to the mill laboratory for analysis. Mill laboratory analysis is limited in the range of analyses that can be performed and in the scope to perform these tests as the primary function of this laboratory is the analysis of cane for payment purposes.

The measurement of sugarcane juice brix in the field (hereafter referred to as “Infield Brixing”) by sampling the middle of a sugarcane stem, has been used by cane growers for some time, however this measurement of brix is inaccurate and has not been previously useful in assessing other crop parameters. This project has focussed on developing infield methods to measure the crop characteristics such as brix, moisture and CCS, which would enable growers to dynamically assess crop condition during the drying-off period.

Infield cane measurement
The cane measurement method developed composes of sampling Brix measurements at five positions along the millable cane stem then interpolating across the entire cane stem to derive the stalk Brix. Brix measurements are collected on a representative number of stalks in an area of the field and used within a sugarcane compositional model (ternary growth model) to derive estimates of crop parameters, such as crop moisture and CCS. This technique was trialled for the 2008 and 2009 seasons and produced results with an accuracy of ±0.90, ±1.04 and ±0.79 units of Brix, moisture and CCS respectively.

Drying-off
Soil moisture was measured at four depths (10cm, 20cm, 40cm and 100cm) using an EnviroSCAN moisture probe. During the 2008 season, eight growers employed their usual drying-off practices, while in 2009, they followed an irrigation scheme that enabled the casual link between soil moisture and CCS to be investigated. The irrigation scheme in 2009 involved growers maintaining a soil moisture content between 25% and 75% plant available water (PAW).

By continual monitoring of crop parameters using the infield method and soil moisture content, the casual link between soil moisture and crop development was analysed to measure the increase in CCS with declining soil moisture – the classical assumption to drying-off. Surprisingly, no casual link relating soil moisture with crop characteristics (other that biomass yield) were observed. The resulting CCS of the cane crops were independent of soil moisture – provided the crop did not become water logged nor drought affected.

Crop CCS was highly correlated to the duration that the crop was grown, post-wet season, to the point where accurate predictions of CCS could be made on time differences alone. This outcome casts some doubt on the traditional assumption of drying-off cane crops to increase CCS. Further analysis of the literature pertaining to drying-off revealed that historically, there is only a 50% to 70% chance that the practice of drying-off increases CCS. This corresponds to a significant probability that drying-off is not a true mechanism to increase CCS in sugarcane crops.

Crop maturity
The infield measurement method provided the most informative measure of crop maturity, being the CCS of the sugarcane stalk. Also using the infield method, a measure of the brix of the bottom internode relative to the top of the millable stem was investigated, and was found to be a more indicative measure of crop maturity than other common indicators such as the number of green leaves.
Irrigation resulting from delayed harvesting
The amount of water to apply to a crop resulting from a delay in harvesting can be directly measured using the historic water usage trends measured by EnviroSCAN moisture probes. The daily crop water usage leading up to the proposed harvest date can be extrapolated beyond the harvest date to give an estimate of how much water is needed - provided that the soil has enough time to dry to reasonable levels to mitigate compaction due to harvesting machinery.

Since there was no direct link between soil moisture content and crop characteristics (Brix, moisture and CCS), crop measurements could not be used to determine water usage. Direct measurement of soil moisture content was sufficient to determine irrigation amounts to accommodate delayed harvesting.
1.0 BACKGROUND

The profile of sucrose concentration along the millable cane stalk has been demonstrated to vary with crop age, and in current cane simulators, different simulated profiles of sucrose variation along the stalk are attributed to the different phenological stages of crop development (Singels, Smit et al. 2005). Use of the sucrose profile has been limited to providing an estimate of the potential sucrose that can be stored in the stem for the cane simulators (Inman-Bamber, Bonnett et al. 2008).

Variation of the sucrose profile can readily be measured in situ and since it changes with phenological development, it provides an adequate measurement to estimate sucrose and biomass accumulation along with cane moisture; the three most important factors necessary to be monitored in drying-off cane to improve sucrose yields. This project is aimed at applying the sucrose variation along the stem as a simple tool to indicate when to dry-off, irrigate, and harvest mature cane in order to improve sucrose yields.

The main cause of over-drying is the lack of current information of the crop status as it is being dried off. Crop indicators such as the number of green leaves correlate to the level of water stress (Inman-Bamber and Smith 2005), however information regarding the stalk composition with regard to these indicators is largely unknown. Further, there is no simple, assessable method to determine the crop composition during the dry-off period.

2.0 OBJECTIVES

This project set out to develop simple measurement methods which could be implemented by cane growers to increase sucrose yields by indicating when to dry-off mature cane crops and when to provide additional irrigation due to delayed harvesting.

Specific objectives were to:
1. Use current knowledge on water-use efficiency and crop-growth cycles to develop preliminary guidelines for the Tableland district that result in increased mature cane biomass yields.
2. Research and integrate measurable biological indicators for changes in sugarcane maturity as a precursor for water stressing to increase sucrose yields.
3. Develop a non-complex irrigation schedule to increase sucrose yields for the Tableland district.
4. Develop irrigation schedules that minimise the risk of sucrose yield decline resulting from delayed harvesting and excessive drying-off.
5. Develop and implement a tool for cane growers that use cane and soil measurements so that best knowledge (1-4) can be implemented and subsequently conveyed to everyday cane-growing practices.
6. Assess carry-over ratoon effects resulting from drying-off.

3.0 METHODOLOGY

BSES, Tableland Sugar Service, CANEGROWERS and nine cane farmers jointly participated in deriving the methods to achieve the project objectives. There was a large emphasis in involving the cane growers in deriving methods which they could employ within their own crops and that could ultimately be adopted by other growers.
3.1 Grower participation
Initially, eight cane growers were involved in the project, and were chosen on the basis that they had perceived positive and negative outcomes from applying drying-off practices to increase CCS. In the second year of the project, one grower was unable to participate and was replaced by another grower.

To gauge grower knowledge regarding irrigation practices and drying-off, a baseline survey was conducted in April 2008 and was followed up at the completion of the project in February 2010. Dissemination of dry-off research findings, both from the project activities and literature findings, was conducted during four workshops held bi-annually. During the bi-annual meetings, the project timetable was altered to reflect each of the growers expected harvest date and to determine the irrigation schedules for the forthcoming season.

During 2008, growers gathered data fortnightly using the Brix stabbing method (below). In the portion of the season leading up to harvesting, growers were collecting data themselves, however once the harvesting season commenced, growers were unable to routinely collect the fortnightly samples. BSES staff were subsequently used to collect data and compensate for the decrease in grower participation.

3.2 Site selection
The cane farms chosen were representative of the majority of soil types in the Tableland district. Sugarcane fields within each farm were selected to encompass the majority of cultivars and available crop classes (Table 1).

Table 1 - Sample site soil, variety and class characteristics with sampling periods

<table>
<thead>
<tr>
<th>Site</th>
<th>Australian soil classification</th>
<th>Variety</th>
<th>Crop class (2008)</th>
<th>Sampling periods</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Red Ferrosol</td>
<td>Q191(°)</td>
<td>1R</td>
<td>01/04/08 – 22/10/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27/05/09 - 13/08/09</td>
</tr>
<tr>
<td>2</td>
<td>Red Ferrosol</td>
<td>Q200(°)</td>
<td>2R</td>
<td>01/04/08 – 11/09/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27/05/09 - 19/08/09</td>
</tr>
<tr>
<td>3</td>
<td>Yellow Chromosol</td>
<td>Q120</td>
<td>2R</td>
<td>01/04/08 – 21/05/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11/03/09 - 27/05/09</td>
</tr>
<tr>
<td>4</td>
<td>Yellow Chromosol</td>
<td>Q120</td>
<td>6R</td>
<td>01/04/08 – 08/10/08</td>
</tr>
<tr>
<td>5</td>
<td>Grey/Brown Sodic Dermosol</td>
<td>Q151</td>
<td>Plant</td>
<td>01/04/08 – 17/06/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11/03/09 - 01/06/09</td>
</tr>
<tr>
<td>6</td>
<td>Grey/Brown Dermosol</td>
<td>Q174(°)</td>
<td>2R</td>
<td>01/04/08 – 04/06/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21/04/09 - 24/06/09</td>
</tr>
<tr>
<td>7</td>
<td>Leptic Tenosol</td>
<td>Q200(°)</td>
<td>1R</td>
<td>01/04/08 – 02/07/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21/04/09 - 15/06/09</td>
</tr>
<tr>
<td>8</td>
<td>Brown/Grey Chromosol</td>
<td>Q174(°)</td>
<td>5R</td>
<td>01/04/08 – 22/10/08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21/04/09 - 17/07/09</td>
</tr>
<tr>
<td>9</td>
<td>Yellow/Brown Ferrosol</td>
<td>Q200(°)</td>
<td>P</td>
<td>21/04/09 – 18/08/09</td>
</tr>
</tbody>
</table>

* Site 9 replaced Site 4 in the 2009 sampling program

3.3 Soil moisture content
Soil moisture content was logged at 15 minute intervals at each site by an EnviroSCAN® soil moisture probe, with sensors located at soil depths of 10, 30, 60 and 100 cm. In the 2008 season, the participating growers dried off their crop according to their own individual practices, while in the 2009 season, multiple irrigations were applied after the wet season so that the soil moisture content did not fall below 25% of the field capacity.
It was hypothesised that crop moisture should trend with soil moisture content during the drying-off cycle. If the hypothesis holds true, then crop moisture should increase after irrigation/rainfall events during the drying-off cycle.

3.4 Sample collection and crop parameter estimation
During the 2008 and 2009 seasons, weekly samples from each site were analysed to determine the Brix, moisture, fibre and CCS crop parameters. Initially, growers provided fortnightly infield measurements and BSES staff collected samples on alternate fortnights. When harvesting commitments increased for growers and impinged on their time, BSES staff increased their sampling frequency to weekly sampling to compensate.

Field samples collected by BSES staff consisted of a bundle of six millable cane stalks which were randomly cut within a ten meter radius of the moisture probe. The six stalk bundles were transported to the Mulgrave Central Mill where measurements where the bundle was sampled using the field Brixing method. The same stalks were passed through a small two roller mill with Brix and pol measurements taken on lead clarified samples of the expressed juice. Green leaves were counted in the field prior to the bundle being sampled and analysed.

For samples measured by growers, a six stalk bundle was cut near the moisture probe. Each stalk was measured using the infield Brixing method, with green leaf numbers also recorded.

Stalk fibre, CCS and moisture values were calculated using the ternary growth model using both the small roller mill Brix value and the derived stem Brix value from the infield method. Crop parameters were estimated by median absolute deviation (MAD) statistics.

3.4.1 Infield Brixing
To determine the Brix content of each individual cane stalk, five Brix readings were taken from the base internode ($b_1$), two internodes up from the base ($b_2$), the middle internode ($b_3$), three internodes down from the top of the millable stalk ($b_4$) and the internode at the top of the millable stalk ($b_5$). Juice was taken from the middle of each internode by a dibbler and the Brix was measured by a handheld PAL digital refractometer. A stalk Brix value was interpolated using the five Brix readings (Appendix 1), from which crop estimates for moisture, fibre and CCS were derived using the ternary growth model.

3.4.2 Ternary growth model
Simplistically, sugarcane consists of just three main constituents: water, soluble solids and insoluble solids (Figure 1). The composition of these constituents is not a random collection of permutations but is well structured; with changes in the composition being defined by a clear functional relationship. If one of the constituents is known, then the remaining two can be calculated using the ternary growth model. For instance, if the soluble solids content, or Brix, is known, then the moisture and insoluble solids (fibre) can be derived. Ternary predictions can be based upon Brix results taken using the infield Brixing method (infield ternary growth modelling).
3.5 Ratooning effects
Repeated measurements taken at the sites over two years were used to assess the effects attributable to drying-off. An additional site within the Site 1 farm was used to investigate the change in CCS and cane yield associated with excessive drying-off. The additional site, denoted as Site 1B, had its irrigations withheld in 2008 and 2009 to simulate typical drying-off strategies which were obtained from the baseline survey.

4.0 RESULTS

4.1 Infield Brixing method
Brix levels in the lower portion of the stem were consistently higher than those in the upper portion, however over time, the measurements taken near the tops approached those from lower in the stalk (Figure 2). A simple average of sampled internode Brix values was not useful in determining the overall stalk Brix since the lower internodes contribute more soluble solids than the upper internodes. The stalk Brix, $B$, can be derived from the sampled internode Brix values by using a weighted sum approach where $w_i$ is the mathematical weighting of $i^{th}$ internode and $b_i$ is the Brix of the $i^{th}$ internode:

$$B = \sum_{i=1}^{s} w_i b_i$$

The weightings can be simply the internode mass relative to the combined mass of the sampled internodes. However, weighing the internode mass in a cane field is impractical so a simple estimate of the internode weights was derived using the relative Brix content:
A refinement in the calculation of the stalk Brix, $B$, is to interpolate the Brix between internodes and integrate the interpolated Brix values across the stalk. Interpolated Brix values can be achieved using Hermite cubic splines where $B$ is the stem Brix, $H_i(b)$ is the $i^{th}$ Hermite cubic spline and $\Theta_i$ is the integrand area as determined by the knot points (sampled internodes) of the splines.

$$B = \sum_{i=1}^{s} \int_{\Theta_i} H_i(b) db$$

Hermite cubic splines are methods of cubic interpolation between data points so that the interpolating curve is minimally flat – meaning that the curvature between the data points is as small as possible for a cubic spline. An example of the Hermite cubic spline for a stalk of cane where the brix has been sampled at five positions along the stem is illustrated in Figure 3.

Figure 2 - Median Brix variation along the stem at for fortnightly sampling periods for four sites in the 2009 season. Lower Brix curves were sampled at the beginning of the respective sampling period, increasing to the upper most curves prior to harvesting.
Both the linear (Equation (2)) and cubic (Equation (3)) interpolation methods gave good predictions of the total stalk Brix with the residual error standard deviation, $\hat{\sigma}_r$, being 0.55 for both methods (Figure 4). The cubic method performed slightly better at the extremities of the range, which was to be expected since the departure from linearity is greatest for low Brix cane.
4.2 Crop parameter estimation
Using the ternary model relationships between Brix and moisture, and Brix to fibre, crop estimates for moisture (Figure 5) and CCS (Figure 6) were derived. The reported infield Brix values were based on the Hermite cubic spline method. Using the six stalk bundles, the residual standard deviation for estimating crop Brix, moisture and CCS were 0.46, 0.53 and 0.40 respectively. This translates to crop estimates within $\pm 0.90$, $\pm 1.04$ and $\pm 0.79$ units of Brix, moisture and CCS.

![Figure 5 - Laboratory moisture compared to the infield moisture as calculated by the integrated Hermite cubic spline/moisture model for data collected in 2009.](image)

![Figure 6 - Laboratory CCS compared to the infield CCS as calculated by the integrated Hermite cubic spline/moisture model for data collected in 2009.](image)
4.3 Soil moisture
During the 2008 and 2009 seasons, the total soil moisture content did not excessively fall below the perceived soil stress level and at most times did not go below 45% of the field capacity (Figure 7). This resulted in a positive net photosynthesis rate during the drying-off period (Park et al., 2005). For both years at all sites, soil moisture was at field capacity at the end of the wet season, and was not subsequently irrigated until the soil moisture content reached 25% of the plant available water (PAW) limit. This led to several drying-off cycles between the end of the wet season and harvesting.

Figure 7 - Summed soil moisture leading to harvest date (2009) for (a) Site 6; (b) Site 9; (c) Site 7; (d) Site 5; (e) Site 8; (f) Site 2; (g) Site 3; (h) Site 1. Top dashed line (---) represents the estimated field capacity and the lower dashed line represents the estimated onset of moisture stress level.
In analysing the soil moisture data at different depths, three effects were observed and were of considerable interest to the participating growers. Soil movement in the shallow topsoil is dominated by three effects:

1. Thermal diurnal gradients resulting in soil moisture flowing in a downwards direction during the day, and then being drawn back to the surface after dusk (Feddes, Kabat et al. 1988);
2. Plant roots being an active moisture sink at depths between 5 cm to 40 cm (Smith, Inman-Bamber et al. 2005);
3. Soil moisture being transferred from depth (1 m) to re-equilibrate the daytime sink of the plant roots (Belmans, Wesseling et al. 1983).

Thermal moisture flow has been reported to occur from hot to cold (Feddes, Kabat et al. 1988). As the top surface heats up during midmorning, soil moisture flows downwards and the reverse effect occurs after dusk; once the topsoil begins to irradiate heat (Figure 8).

![Figure 8 - Soil moisture probes at 10 cm and 30 cm over a five day period with hourly sampling](image)

Soil moisture extraction occurred primarily within the top 60 cm of the soil profile. Evidence for this is a lag between measured moisture at 100 cm with the soil probes at 10, 30 and 60 cm. To negate the thermal variation phenomena, interpolated soil moisture values for the top 60 cm of soil were used (Figure 9). The lag times between soil moisture being withdrawn at 10-60 cm by the plant and soil moisture being partially replenished (to establish equilibrium) from depth, are typically two to four hours depending on soil type. Heavier soils such as those with higher clay contents, respond more slowly than the sandy soils.
4.4 Soil moisture and crop moisture

Drying-off practices leading into the harvesting period is commonly believed to be a mechanism to increase CCS content. The mechanism by which this is thought to occur is based on the assumption of higher sensitivity to water stress of expansive growth compared to photosynthesis (Inman-Bamber and Smith, 2005). When expansive growth is suppressed by water stress, photo-assimilates (sucrose) which would otherwise be required for leaf and stalk expansion are diverted to the stalk for storage. Naturally, this increase in sucrose content is at the expense of total crop biomass, but previous simulation studies have demonstrated economic advantages could be gained by minimising transportation costs by optimally drying-off to reduce plant moisture (Robertson, Muchow et al. 1999; Inman-Bamber 2004).

In the “linear” water stress model (Inman-Bamber and Smith 2005), as the plant gains biomass, subsequent daily transpiration usage increases and increases the water stress on the plant. This leads to an exponential decline in the rate of biomass accumulation coupled with an exponential increase in sucrose accumulation. Manifestations of this hypothesis would be to observe exponential increases in Brix (or alternatively exponential declines in plant moisture) with declining soil moisture. Additionally, it would be expected that the rate of Brix accumulation (or plant moisture) would be altered by irrigation events which would alleviate water stress. An indicative trend would be to see increases in crop moisture being accompanied with irrigation events.

In the 2008 and 2009 seasons, plant moisture was not observed to track causally with changes in total soil moisture – many examples were observed where increases in soil moisture were not always accompanied with increases in crop moisture (Figure 10).
Increases in crop moisture have previously been related to increases in soil moisture but only when the soils have been in extreme water stress (Inman-Bamber and Spillman 2002).

Figure 10 - Typical total soil moisture compared with crop moisture for four sites in 2009

These unexpected results prompted an investigation of previous literature to in order to relate this result with previous findings. Historically, drying-off experiments have been inconclusive in confirming or rejecting the applicability of drying-off as a mechanism to increase CCS. One report described a survey of 84 field trials which confirmed that 64% of the trials resulted in statistically significant increases in CCS through drying-off soils (Robertson and Donaldson 1998). A binomial treatment of this data shows that the 95% confidence interval for the probability that drying-off is a real phenomena is between 50% and 75% (mean probability is 64%). This analysis points to a potentially real scenario that drying-off soils may not be a mechanism to increases CCS.

4.4.1 Soil moisture guidelines

In the latter half of the project, a set of quantifiable soil moisture guidelines were derived with the aim of mitigating yield loss due to water stress from either too much or too little moisture. The guidelines developed were:

- Maintain post wet season soil moisture between 75% and 25% plant available water (PAW) levels. These 75% and 25% levels were established for each EnviroSCAN based on historic measurements but can be initially estimated as 7/8 and 5/8 of the field capacity, as measured during the wet season;
- Measuring the rate of soil moisture decline between irrigations to estimate the time required to reduce soil moisture for satisfactory harvesting;
- Post harvesting, return the soil moisture to a level above the 25% PAW, preferably to approximately 50% PAW.

The last guideline is to encourage ratooning whilst maintaining the potential for soil moisture capture during the upcoming wet season.
4.5 Maturity indices
Cane maturity is generally a measure of the state of cane relative to the maximum potential of the cane. This potential can relate to the total amount of sugars, sucrose or total biomass – however in this project, we have defined maturity to relate to the minimum cane moisture point reached. There are many methods to calculate cane maturity such as core sampling to determine reducing sugars, but within this project, we have only considered the use of simple indices such as green leaf numbers (Inman-Bamber 2004) and brix measurements (B. V. Nath 1935) for the relative measure of cane maturity.

4.5.1 Mean number of green leaves
Changes in the number of green leaves have been suggested as a method to determine the optimal time for crop harvest (Inman-Bamber 2004). A decrease by three to four green leaves from the maximum number of leaves has been suggested as an indication for the best time to harvest corresponding to an optimal drying-off period. In this project, it was observed that in all cases, a long term decrease in the mean number of green leaves is associated with an overall decrease in stem moisture (Figure 11).

![Figure 11 - Plot of mean number of green leaves against changes in stem moisture for four field sites: (a) Site 4, (b) Site 5, (c) Site 1, and (d) Site 6.](image)

The trend in changes in green leaf numbers and stem moisture is most marked during transitional changes in stem moisture around 69%, at which point, radical changes in the mean number of green leaves occur within the crop (Figure 12). Once the stem reaches 69-70% moisture, a decrease the mean number of green leaves by two to four was observed.
Sequential measurement of the mean number of green leaves towards harvest was investigated to determine if their number declines with crop age (Figure 13). However, no consistent trend across fields indicating crop maturation was evident. In some instances, the mean number of green leaves decreased towards harvest (Figure 13 (b) and (c)), however, the majority of fields did not exhibit a clear trend (Figure 13 (a) & (d) being typical examples).

A change in the number of green leaves appears to act as a non-destructive indicator for a decrease of 71% stem moisture down to 68% stem moisture. Below 68% stem moisture, there was no observable trend with green leaf numbers stem moisture.

Figure 13 - Plots of mean number of green leaves against the number of days leading to harvest for four field sites: (a) Site 4, (b) Site 5, (c) Site 1 and (d) Site 2.
4.5.2 Stem brixing

Measurements of stem brix have been used as a maturity index since 1935 (B. V. Nath 1935), where the ratio between the top and bottom brix measurements was used as a measure of cane maturity. Quite simply, when the ratio equals one, the sugarcane stalks was considered to have reached maturity.

In this project, five brix measurements along the stem, top, top -2, middle, bottom +1 and bottom nodes, were sampled using a dibbler and the Brix recorded using a hand-held digital refractometer. Brix ratio measurements in this project were calculated from the brix reading taken from two nodes up from the base and two nodes down from the growing point. These nodes were generally free from pest damage and would be easily and reliably recorded.

Generally, the brix ratio trended with cane stem moisture with a decrease in stem moisture accompanying an increase in brix ratio within a crop (Figure 14). Brix ratio variation with plant moisture values below 68% does not appear to trend as readily as those recorded above 68%. Sequential brix ratio measurements leading up to harvest demonstrated a general trend of increasing the brix ratio towards unity as the harvest date was approached (Figure 15).

Figure 14 - Plot of laboratory cane moisture % variation with brix ratio (top/bottom) for four field sites: (a) Site 4, (b) Site 5, (c) Site 1 and (d) Site 2
Figure 15 - Plot of Brix ratio against days remaining until harvest for four field sites: (a) Site 4, (b) Site 5, (c) Site 1 and (d) Site 2

4.6 Crop moisture and days till harvest
Crop moisture was observed to monotonically decrease leading to the harvest date. An analysis of crop moisture and days remaining before harvest was performed by a linear mixed effects (LME) model using the nlme library in the "R" statistical software program. The sampled site and year (nested in site) constituted as random effects with the model. This type of data fits the framework of an Analysis of Co-Variance (ANCOVA) model – a type of LME model.

Figure 16 - Plot of crop moisture percentage against days: (a) Crop moisture leading to harvest date, (b) Day of year corrected for Year and Farm effect. Individual farms denoted as follows: (+) Site 6, (+) Site 4, (*) Site 9, (□) Site 7, (○) Site 5, (△) Site 8, (▷) Site 2, (★) Site 3 and (x) Site 1. Solid icons have been used for the 2008 season with clear icons for the 2009 season.
Within the ANCOVA model, the slope can either be fixed for each site/year or each can have a common slope but with random perturbations about the mean slope. The former model has the slope as a fixed factor while the latter model is said to have the slope as a random factor. Comparison between the fixed and random models is highly in favour of the random model ($P = 0.0044$).

In the random effects ANCOVA model, crop moisture correlated negatively with days remaining before harvest (slope = -0.063 % moisture per day, $\hat{\sigma}_s^2 \approx 0.004$, $P < 0.000$). The standard deviation of the slope for the within farm variation was $\hat{\sigma}_{f,s}^2 \approx 0.007$ and the within year variation was $\hat{\sigma}_{v,y}^2 \approx 0.008$. This indicates that the slope varies randomly by values up to $\pm 0.014$ from farm-to-farm and $\pm 0.016$ year-to-year.

By correcting for the random offsets related to sites/year, changes in crop moisture can be estimated from the change in the number of days before harvest. However, time itself is not a true factor so other natural phenomena must be influencing the decrease in crop moisture observed. The concept of “thermal time” may have some influence but due to the large variation in the growth cycles of the different sites (up to five months), thermal time can be discounted as the major contributing factor.

Thermal time changes sinusoidally throughout the year, so the rate at which thermal time would influence cane crop characteristics should also exhibit a sinusoidal nature – or at least different rates of decline in crop moisture at different times through the year. However, all sites exhibited the same rate of decline of crop moisture with time (number of days before harvest) irrespective of the time of year, hence thermal time cannot be the sole contributor. A similar argument can be applied to mitigate all other observable environmental factors such as wind speed, sunshine hours, relative humidity and others, however, variables such as latitude and altitude may change the slope of the linear regression. This leaves unknown physiological mechanisms within the cane plant as the cause for the decline of crop moisture over time.

### 4.7 Yield, CCS and Ratoon Effects

Both seasons reported above average yields (tonnes cane per hectare) for nearly all sites, however, CCS was consistently below average at most sites (Table 2). Of note is the yield difference between Site 1 and Site 1B, which can be attributed to the reduction of applied irrigation at Site 1B post wet season. It was also noted that the ratooning crop at Site 1B was delayed by approximately three weeks compared to that at Site 1, which was harvested in 2008 at the same time. The comparisons between Site 1 and Site 1B also illustrate that the same CCS level is achieved even though only one field underwent a drying off cycle for the purposes of increasing CCS.
<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crop Yield (tc/ha)</td>
<td>Site CCS</td>
</tr>
<tr>
<td>1</td>
<td>Q191*</td>
<td>182.5*</td>
<td>14.2</td>
</tr>
<tr>
<td>1B</td>
<td>Q191*</td>
<td>141.2*</td>
<td>13.9</td>
</tr>
<tr>
<td>2</td>
<td>Q200*</td>
<td>146*</td>
<td>14.4</td>
</tr>
<tr>
<td>3</td>
<td>Q120</td>
<td>120</td>
<td>12.2</td>
</tr>
<tr>
<td>4</td>
<td>Q120</td>
<td>74.7</td>
<td>14.7</td>
</tr>
<tr>
<td>5</td>
<td>Q151</td>
<td>144.7</td>
<td>13.4</td>
</tr>
<tr>
<td>6</td>
<td>Q200*</td>
<td>125.4</td>
<td>12.3</td>
</tr>
<tr>
<td>7</td>
<td>Q200*</td>
<td>135.6*</td>
<td>12.9</td>
</tr>
<tr>
<td>8</td>
<td>Q174*</td>
<td>92.1</td>
<td>13.0</td>
</tr>
<tr>
<td>9</td>
<td>Q200*</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Harvester tc/ha values may be inflated by values up to 20% of the true value.
†Weekly mill average CCS used in the absence of weekly variety mill CCS.
‡ Season mill average tc/ha used in the absence of weekly variety mill tc/ha.
4.8 Grower surveys
A baseline survey was conducted at the beginning of the project for the eight initial cane growers in order to identify grower knowledge and practices related to drying-off processes leading into the harvest period. Conclusions from this baseline survey were as follows:
- All participating growers perceived that drying-off could lead to increases in CCS;
- All had negative outcomes resulting from drying-off too much – this either caused the crop to ferment and/or die-off;
- Growers will irrigate the crop if the original harvesting date was delayed by three or more weeks. No irrigation would be performed if harvesting was delayed by less than three weeks;
- Growers primarily used soil moisture probes or BSES irrigation advice to determine when and how much water to apply;
- Leaf conditions were used to assess drying-off behaviour of the crop, i.e. the crop was considered to be dried-off when the leaves were yellow;
- All growers did not know how drying-off physically affects the crop, other than the perceived increase in CCS they were anticipating;
- There was little understanding of soil moisture and sugarcane root structure relationships – a commonly believed misconception is that all roots can provide the plant with soil moisture, even at depths of six or more meters.

Over the duration of the project, a series of grower meetings were held to disseminate project research findings. These findings can be summarised as:
- Better understanding moisture movements through the soil and the driving mechanisms for moisture movement;
- Understanding where sugarcane roots draw moisture from the soil and how soil moisture is replenished in the root zone during the cropping and irrigation process;
- Compositional modelling of sugarcane – how CCS can be predicted from Brix measurements;
- Measurable effects of CCS attributable to withholding irrigation during drying-off;
- Developing soil moisture guidelines in order to:
  - maintain active crop development;
  - allow harvester access;
  - mitigate over-drying risk due to delayed harvesting.

At the final grower meeting, a survey of project learning objectives was conducted, with the results summarised as follows:
- All growers changed their perceptions on their idea of drying-off processes to increase crop CCS;
- Growers unanimously agreed that manipulating of soil moisture should be done to increase crop yield, allow harvest access and to improve the strike of subsequent ratooning crop;
- The use of soil moisture probes adds greatly to irrigation management practices, particularly for:
  - Irrigations required due to delayed harvesting;
  - Frequency amount of irrigation required post wet season;
  - To estimate the expected time required to dry-off the soil to mitigate soil compaction from harvesting;
  - Irrigation post harvesting to encourage crop ratooning;
- CCS predictions made from the ternary growth model enable better harvesting decisions;
- Seven of the nine growers would like to see this research adopted by irrigation services or by BSES Extension staff, while the remaining two growers would prefer to implement the research themselves;
• Growers would only use crop leaf condition to identify extreme crop water stress and not use it as an indicator of drying-off crop maturity.

5.0 OUTPUTS

5.1 Crop parameter measurement
This project has produced a practical infield method to measure Brix, moisture, fibre and CCS crop parameters. The measurement, when adequately coupled with representative crop sampling, is accurate to within one unit of measurement for each of the constituents as compared to the sugar mill laboratory results. Additionally, the infield measurement provides useful crop maturity information - particularly the ratio of Brix of the top and bottom stalk internodes.

Farmers and researchers can use this method to elucidate crop characteristics cheaply, accurately and quickly. The sugarcane compositional model coupled with the mathematics used to derive stalk brix via the infield dibbler Brixing method has been incorporated into a Microsoft Excel spreadsheet and has been made available to the participating growers. In order to implement the infield Brixing method, the only requirements besides the Microsoft Excel spreadsheet are a dibbler and a handheld refractometer, which are available at a total cost of less than $200.

A portable two roller mill has been mounted into a trailer as an alternative to the infield dibbler Brixing method. The small mill method enables a physical integration of stalk Brix without the need to interpolate and mathematically integrate. Additionally, the portable mill can process a six stalk bundle more rapidly and with less physical labour. The capital cost to manufacture the portable small mill is approximately $8 000 - $10 000.

5.2 Soil moisture
The movement of soil moisture pertaining to agricultural crops has been illustrated and fits with the current best knowledge. The soil moisture movements shown in this project are relatively unknown in this generation of the sugarcane industry, however the concepts are well known in other areas such as soil hydrology. In this regard, introducing these concepts to farmers and sugarcane researchers alike does provide a useful contribution to the sugarcane industry. The utility of soil moisture is paramount in maintaining crop production and the relationships between soil moisture and plant roots need to be better communicated in order to guide further research and growing practices.

Guidelines for soil management are recommended for crop development pre- and post-wet seasons in order to yield a greater crop size rather than any other perceived benefit. Soil moisture probes such as the EnviroSCAN can give quantifiable measurements from which to make more informed irrigation management decisions.

5.3 Drying-off
The concept of drying-off is best left for harvesting considerations only, rather than as a tool to increase crop CCS. By continually measuring crop moisture and soil moisture, the causal link between drying-off and crop development has been questioned and additional research of the current literature further undermines the commonly held assumption of the positive effects attributed to drying-off.

The effects of prolonged drying-off, commonly known as drought, are previously well established and very little positive benefit can be gained from this practice. The effect of a relative short drying-off period, less than six weeks, has no effect on crop development other than those attributable to biomass yield considerations.
5.4 Crop parameter prediction
Once crop parameters have been measured after the wet season, subsequent crop Brix, moisture, fibre and CCS development can be adequately predicted by using a simple linear regression with the number of days being the independent variable.

5.5 Grower participation
Nine growers actively participated in the project and demonstrated thorough their actions, an increased understanding of crop development and soil health. Growers were initially proactive in gathering data using the infield method, however once the harvesting season commenced, many were unable to commit the time required towards the project. This availability of grower time during the pre-harvest period does however provide an opportunity for growers to use the infield method to predict crop development into the harvesting season, thereby giving the growers more information that can be used for harvesting scheduling.

All growers attended the bi-annual meeting to learn of the research findings from the project regarding:
- Soil health and soil moisture manipulation cycles to improve yield;
- The perceived benefits of drying-off;
- Crop development using the sugarcane compositional model.

6.0 EXPECTED OUTCOMES

6.1 Adoption by growers
To promote the infield Brixing methods using either the dibbler or small mill version, a series of field days and exhibitions have been scheduled in 2010 in Bundaberg, Innisfail and Mackay. Promotion in the Tableland region will be done by a bus trip run by BSES and CANEGROWERS in late April 2010. The tour will consist of visits to multiple sites of interest in the region, with the infield measurement method demonstrated at a number of these sites.

The research findings regarding soil moisture movement and drying-off will be relayed to growers at field days/exhibitions and on the bus tour. An article in the BSES Bulletin has been published to provide additional coverage for the project outcomes. Project findings are also being relayed to BSES Extension staff and Tableland irrigation services (Fabian Gallow).

All of the participating growers have indicated that they would like to purchase additional EnviroSCAN probes to continue using the soil moisture guidelines and the infield brixing method developed in the project.

6.2 Adoption by researchers
BSES research stations are trialling the portable small mill for use in variety selection trials. A series of meetings and interactions with growers are planned for 2010, in particular in conjunction with a number of BSES field days. These interactions will also promote the availability and utility of the equipment with BSES Extension Officers.

7.0 FUTURE NEEDS AND RECOMMENDATIONS
Nil
8.0 PUBLICATIONS ARISING FROM THE PROJECT

A formal draft publication has been prepared and is under internal BSES review. It describes many of the outcomes of this work and will be submitted for publication in an appropriate journal in due course. A copy will be forwarded to the SRDC upon submission.

9.0 ACKNOWLEDGMENTS
BSES Limited would like to acknowledge the following contributions towards this project:

- CANEGROWERS for their administrative assistance and the use of their conference room facilities
- Mulgrave Central Mill for in-kind use of their mill laboratory
- Tablelands Sugar Services for their financial contribution and special interest in the topic of drying-off
- Bundaberg Sugar (Tableland Mill) for providing weekly yield and CCS data
- The nine participating growers for their input, diligence, interest and contribution to data collection. Without their enthusiasm, the project could not have achieved the outcomes listed in this report.

10.0 REFERENCES