SEASON RAINFALL AND CROP VARIABILITY
IN THE MACKAY REGION

By

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Abstract

AVERAGE CROP YIELD in the Mackay region in recent seasons (2008–2010) was 73 t/ha. This can be compared to the period from 1994 to 1998 when average crop production was 99 t/ha. This difference in crop production is of great concern to all sectors of the industry. This paper reports on an investigation into the effect of seasonal weather variability on the crop in the Mackay region. Seasonal conditions are one possible cause of the difference between the two periods. Total rainfall, effective rainfall, indicators of rainfall distribution, waterlogging, thermal time and solar radiation were used to define seasonal conditions. Analysis showed a significant correlation between seasonal weather parameters and crop variability in the Mackay region over the last two decades. Crop simulation over the period also suggested weather conditions were more conducive to crop growth in the mid 1990s than recently. Correlations between crop yield and rainfall variability for 20 year rolling periods commencing in 1951 were used in an attempt to determine the effect of rainfall variability on the Mackay crop over the longer term (1950–2010). The analysis suggested that the correlation between crop yield and rainfall variability had strengthened over time. This could imply that as management practices and varieties have improved, seasonal weather conditions becomes a more important driver of crop production in the region. However, industry expansion onto poorer soils and the condition of the soil after long term monoculture may also have affected the result. Overall, the investigation suggests that adaptation to seasonal weather variability is an important factor in industry sustainability. Management practices that allow flexibility in this regard, particularly irrigation, drainage, farming systems, timing of operations and suitable varieties need further investigation.

Introduction

Australia’s sugarcane crop is grown in high-rainfall zones and irrigated districts along the coastal plains and river valleys at several locations on 2100 km of Australia’s eastern coastline–between Mossman in far north Queensland and Grafton in New South Wales.

The crop experiences a diverse range of climatic conditions associated with the geographic spread in production. Mean annual rainfall exceeds 3000 mm in Innisfail, Tully and Babinda and is lower than 1000 mm at Ayr and Mareeba (Kingston, 2000).

Management practices in each district differ according to climatic conditions, notably irrigation requirements which range from 0 ML/ha in wet districts to >10 ML/ha at Ayr (Ham et al., 2000).
Within each district significant seasonal weather variability is also experienced. This variability is associated with both short term patterns (2.5–8 years) such as the El Niño-Southern Oscillation (ENSO), longer term (15–30 years) low frequency signals such as the Inter-decadal Pacific Oscillation (IPO) (Jaffres and Everingham, 2005) and related yet unpredictable events such as tropical lows and cyclones. This seasonal weather variability affects sugarcane production and thus the profitability and sustainability of the industry.

Crop yields in the Mackay region over the last three seasons (2008–2010) have been below average (1990–2010). Yields in these recent seasons have also been lower than the above average yields achieved in the mid 1990s (1994–1998).

This apparent loss in production is of great concern to all sectors of the Mackay industry. Possible explanations of the cause of this difference in production needed investigation. This paper reports on work conducted to determine the influence of seasonal weather variability on sugarcane production in the Mackay district.

Methods

Weather and yield data

Weather data were sourced from the Bureau of Meteorology sites at Te Kowai, Eton and Farleigh. Daily rainfall (mm), daily solar radiation (MJ/m²) and maximum and minimum temperatures (°C) were used. Yield data were obtained from BSES Mill statistics, Canegrowers and BSES QCaneSelect.

Calculation of seasonal weather parameters

For the purposes of determining the conditions experienced by a crop in a season, and thereby allowing comparison among seasons, weather parameters for the period from 1 July to 30 June were calculated (season).

This represents the period during which the main growth phases (establishment, tillering, stalk elongation, maturation) of the crop occur. Data from the three weather stations were averaged to represent the region’s conditions.

Thermal time (°D) was calculated using the method described by Baskerville and Emin (1969) and a base temperature of 9 °C, as is used in the Agricultural Production Systems sIMulator (APSIM) sugar module (www.apsim.info/wiki/Sugar.ashx). Season solar radiation was calculated by summing daily data.

The average of the Farleigh and Eton sites only was reported as solar radiation data was not available from the Te Kowai weather station. Daily rainfall was summed to calculate total season rainfall. Daily rainfall was summed from 1 December to 30 April to calculate wet season rainfall.

The percentage of rain falling during the wet season was also calculated from equation 1 as an indicator of rainfall distribution.

Equation 1: \[ \text{% wet season} = \frac{\text{total wet season}}{\text{total season rainfall}} \times 100 \]

A high percentage of rain falling during the wet season would represent poorly distributed rainfall and a low percentage would represent well distributed rainfall. Effective rainfall was calculated for soils with plant available water capacity (PAWC) of 60, 80, 100 and 120 mm using all three rainfall data sets and a standard crop.

The results from these calculations, both PAWC and rainfall dataset, were averaged to represent the district effective rainfall. Evapotranspiration (Et) data in Table 1 were used in the calculation.
Table 1—Evapotranspiration (Et) for a standard crop (highlighted cells) used in all seasons to estimate effective rainfall for the Mackay region.

<table>
<thead>
<tr>
<th>Month</th>
<th>Evaporation (mm/day)</th>
<th>Bare ground</th>
<th>0.25 canopy</th>
<th>0.5 canopy</th>
<th>0.75 canopy</th>
<th>Full canopy</th>
<th>Crop maturing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evapotranspiration (mm/day)</td>
<td>0.3*</td>
<td>0.5*</td>
<td>0.6*</td>
<td>0.7*</td>
<td>0.85*</td>
<td>0.65*</td>
</tr>
<tr>
<td>Jul</td>
<td>3</td>
<td>0.9</td>
<td>1.5</td>
<td>1.8</td>
<td>2.1</td>
<td>2.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Aug</td>
<td>3.7</td>
<td>1.1</td>
<td>1.9</td>
<td>2.2</td>
<td>2.6</td>
<td>3.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Sep</td>
<td>4.8</td>
<td>1.4</td>
<td>2.4</td>
<td>2.9</td>
<td>3.4</td>
<td>4.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Oct</td>
<td>5.8</td>
<td>1.7</td>
<td>2.9</td>
<td>3.5</td>
<td>4.1</td>
<td>4.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Nov</td>
<td>6.3</td>
<td>1.9</td>
<td>3.2</td>
<td>3.8</td>
<td>4.4</td>
<td>5.4</td>
<td>4.1</td>
</tr>
<tr>
<td>Dec</td>
<td>6.2</td>
<td>1.9</td>
<td>3.1</td>
<td>3.7</td>
<td>4.3</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Jan</td>
<td>5.5</td>
<td>1.7</td>
<td>2.8</td>
<td>3.3</td>
<td>3.9</td>
<td>4.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Feb</td>
<td>5.1</td>
<td>1.5</td>
<td>2.6</td>
<td>3.1</td>
<td>3.6</td>
<td>4.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Mar</td>
<td>4.8</td>
<td>1.4</td>
<td>2.4</td>
<td>2.9</td>
<td>3.4</td>
<td>4.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Apr</td>
<td>4.0</td>
<td>1.2</td>
<td>2.0</td>
<td>2.4</td>
<td>2.8</td>
<td>3.4</td>
<td>2.6</td>
</tr>
<tr>
<td>May</td>
<td>3.2</td>
<td>1.0</td>
<td>1.6</td>
<td>1.9</td>
<td>2.2</td>
<td>2.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Jun</td>
<td>2.8</td>
<td>0.8</td>
<td>1.4</td>
<td>1.7</td>
<td>2.0</td>
<td>2.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*Sugarcane crop factors (Holden, 1998)

Effective rainfall for a given day (day\(_x\)) was estimated from the following equations:

**Equation 2:** If daily rainfall (day\(_x\)) ≤ soil PAWC–soil moisture (day\(_{x-1}\)):

effective rainfall = daily rainfall

**Equation 3:** If daily rainfall (day\(_x\)) > soil PAWC–soil moisture (day\(_{x-1}\)):

effective rainfall = soil PAWC–soil moisture (day\(_{x-1}\))

**Equation 4:** soil moisture (day\(_x\)) = soil moisture (day\(_{x-1}\))–evapotranspiration (day\(_x\)) +
effective rainfall (day\(_x\))

An example of this calculation is shown in Table 2. The example is for a soil with a PAWC of 100 mm, which was filled to capacity on 20 September 2011. These calculations may overestimate effective rainfall as rainfall intensity cannot be accounted for from daily rainfall data.

Table 2—Estimation of effective rainfall for a soil with PAWC of 100 mm.

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain (mm)</th>
<th>Et (mm)</th>
<th>Soil moisture (mm)</th>
<th>Effective rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/09/11</td>
<td>2.4</td>
<td>18.3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>19/09/11</td>
<td>2.4</td>
<td>15.9</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>20/09/11</td>
<td>112.5</td>
<td>2.4</td>
<td>97.6</td>
<td>84.1</td>
</tr>
<tr>
<td>21/09/11</td>
<td>31.6</td>
<td>2.4</td>
<td>97.6</td>
<td>2.4</td>
</tr>
<tr>
<td>22/09/11</td>
<td>2.4</td>
<td>95.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>23/09/11</td>
<td>18.2</td>
<td>2.4</td>
<td>97.6</td>
<td>4.8</td>
</tr>
<tr>
<td>24/09/11</td>
<td>0.8</td>
<td>2.4</td>
<td>96.0</td>
<td>0.8</td>
</tr>
<tr>
<td>25/09/11</td>
<td>2.4</td>
<td>93.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>26/09/11</td>
<td>2.4</td>
<td>91.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>163.1</td>
<td>21.6</td>
<td>NA</td>
<td>92.1</td>
</tr>
</tbody>
</table>

The percentage of rainfall that was estimated to be effective was also calculated from equation 5:

**Equation 5:** \% effective = effective rainfall/total rainfall × 100

The percentage of rainfall calculated as being effective was used as an indicator of seasons with excessive waterlogging, run-off or drainage, with the outcome being soil type dependant. The
Mackay region has a large proportion of soils with poor drainage characteristics due to many soils having B horizons with high clay content.

**Crop simulation**

The APSIM sugar module (Keating *et al.*, 1999) was used to simulate yield for the period from 1990–2010. Crop inputs were kept constant across seasons, thus allowing a comparison of the effect of seasonal weather conditions on sugarcane yield. Simulations were conducted using weather data from the Farleigh weather station and three soil types: Chromosol (PAWC = 88 mm), Vertosol (PAWC = 113 mm) and a Dermosol (PAWC = 103 mm). The crop (Q124) consisted of a plant and four ratoons, and received 200 kg N/ha.

The season the crop commenced was staggered so that a plant and four ratoon crops were grown in each season. Data from the soil types and crops were averaged to represent the region’s yield in a season. Irrigation availability was adjusted until simulated yields were similar to actual region yields. An application of 1 ML/ha was used, and is similar to the region’s average allocation.

**Statistical analysis**

Seasonal weather data and yield for the period from 1990–2010 were analysed using multiple linear regression (GenStat 10.1). Cane yield was used as the response variate and climatic factors as predictor variables. Long-term data (1950–2010) were analysed in a number of ways in order to reduce the effect of other, non-weather related, changes over the period. Analyses were performed for 20 year rolling periods commencing 1951–1970.

Initially cane yield was used as the response variate and rainfall parameters (total, effective, % effective % wet season) were used as predictor variables. The ‘All-subsets Regression’ option in Genstat was used to determine the combination of predictor variables that accounted for the highest percentage of variation.

The analysis was repeated with the inclusion of the previous season’s yield as a predictor variable. This was done in order to account for increasing yield over time and because a season’s yield is not independent. A curve was also fitted to the long term yield data and the residuals used as an indicator of crop variability.

The analysis was conducted using the residual as the response variate and rainfall parameters as predictor variables. This analysis was also repeated using the residual from the previous season as a predictor variable.

**Results and discussion**

Approximately 72 000 ha of sugarcane is harvested annually in the region around Mackay. Average annual production for the period 1990–2011 was 80 t/ha.

In this period, the season with the lowest average production was 1991 at 48 t/ha and the season with the largest average production was 1998 at 107 t/ha (Figure 1). This 59 t/ha range in average cane production results in large differences in profitability among seasons across the value chain.

There are numerous factors that can influence crop yield in a season. Calculated seasonal weather parameters from 1990–2011 are shown in Table 3. The 1991 season experienced low effective rainfall but high total rainfall.

The majority of rain fell during a short period during the wet season causing severe waterlogging, indicated by a very high % wet season and very low % effective rainfall. In 2000 and 2001 the outbreak of orange rust in Q124 reduced yields (Magarey *et al.*, 2001). These seasons also experienced above average total rainfall.
Fig. 1—Average sugarcane (TCH) and sugar (TSH) produced in the Mackay region for the period from 1990–2011. Yield data for 2011 are preliminary.

Table 3—Sugarcane production and seasonal weather parameters for the Mackay region from 1990–2011. Calculated from BOM data and equations 1–5.

<table>
<thead>
<tr>
<th>Season</th>
<th>Effective rain (mm)</th>
<th>Total rain (mm)</th>
<th>% Wet season</th>
<th>% Effective</th>
<th>Thermal time (cum. °D)</th>
<th>Solar radiation (cum. MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>709</td>
<td>1606</td>
<td>60</td>
<td>44</td>
<td>4990</td>
<td>7274</td>
</tr>
<tr>
<td>1991</td>
<td>676</td>
<td>3269</td>
<td>94</td>
<td>21</td>
<td>4955</td>
<td>7153</td>
</tr>
<tr>
<td>1992</td>
<td>700</td>
<td>868</td>
<td>66</td>
<td>81</td>
<td>5166</td>
<td>7730</td>
</tr>
<tr>
<td>1993</td>
<td>743</td>
<td>1090</td>
<td>85</td>
<td>68</td>
<td>5148</td>
<td>7559</td>
</tr>
<tr>
<td>1994</td>
<td>921</td>
<td>1216</td>
<td>68</td>
<td>76</td>
<td>5121</td>
<td>7270</td>
</tr>
<tr>
<td>1995</td>
<td>755</td>
<td>931</td>
<td>75</td>
<td>81</td>
<td>5105</td>
<td>7515</td>
</tr>
<tr>
<td>1996</td>
<td>888</td>
<td>1223</td>
<td>69</td>
<td>74</td>
<td>5195</td>
<td>7275</td>
</tr>
<tr>
<td>1997</td>
<td>924</td>
<td>1517</td>
<td>75</td>
<td>61</td>
<td>4951</td>
<td>7446</td>
</tr>
<tr>
<td>1998</td>
<td>873</td>
<td>1200</td>
<td>73</td>
<td>74</td>
<td>5160</td>
<td>7239</td>
</tr>
<tr>
<td>1999</td>
<td>1042</td>
<td>2078</td>
<td>68</td>
<td>51</td>
<td>5155</td>
<td>6782</td>
</tr>
<tr>
<td>2000</td>
<td>926</td>
<td>2014</td>
<td>79</td>
<td>46</td>
<td>4924</td>
<td>6873</td>
</tr>
<tr>
<td>2001</td>
<td>908</td>
<td>1696</td>
<td>57</td>
<td>54</td>
<td>4966</td>
<td>7213</td>
</tr>
<tr>
<td>2002</td>
<td>757</td>
<td>1002</td>
<td>67</td>
<td>76</td>
<td>5272</td>
<td>7787</td>
</tr>
<tr>
<td>2003</td>
<td>574</td>
<td>1020</td>
<td>78</td>
<td>56</td>
<td>5070</td>
<td>7679</td>
</tr>
<tr>
<td>2004</td>
<td>671</td>
<td>810</td>
<td>84</td>
<td>85</td>
<td>5275</td>
<td>7679</td>
</tr>
<tr>
<td>2005</td>
<td>805</td>
<td>1196</td>
<td>68</td>
<td>68</td>
<td>5114</td>
<td>7614</td>
</tr>
<tr>
<td>2006</td>
<td>852</td>
<td>1075</td>
<td>67</td>
<td>81</td>
<td>5337</td>
<td>7401</td>
</tr>
<tr>
<td>2007</td>
<td>939</td>
<td>1673</td>
<td>71</td>
<td>57</td>
<td>4934</td>
<td>7340</td>
</tr>
<tr>
<td>2008</td>
<td>681</td>
<td>2018</td>
<td>90</td>
<td>34</td>
<td>4917</td>
<td>7224</td>
</tr>
<tr>
<td>2009</td>
<td>817</td>
<td>1762</td>
<td>87</td>
<td>47</td>
<td>5067</td>
<td>7056</td>
</tr>
<tr>
<td>2010</td>
<td>763</td>
<td>1920</td>
<td>90</td>
<td>40</td>
<td>5178</td>
<td>7343</td>
</tr>
<tr>
<td>2011</td>
<td>1089</td>
<td>3521</td>
<td>72</td>
<td>30</td>
<td>4975</td>
<td>7109</td>
</tr>
<tr>
<td>Average</td>
<td>818</td>
<td>1577</td>
<td>75</td>
<td>59</td>
<td>5090</td>
<td>7343</td>
</tr>
</tbody>
</table>

The period from 2008–2010 had a similar seasonal ‘signature’ to 1991 i.e. characterised by low effective rainfall with above average total rainfall and poor distribution. In 2011 rainfall was more evenly distributed but it was also the wettest season on record (1908–2011). Significant rain events occurred well before the traditional wet season, particularly in September, and continued until the end of March. Crops were severely waterlogged for long periods; radiation and thermal time were below average.
Large amounts of plant cane failed. These conditions could also have had indirect impacts on crop growth through nitrogen use efficiency, weed management and follow-on effects on the crop due to wet harvesting conditions during 2010.

Sugarcane yield in recent seasons (2008–2010) is of great concern to the local industry. The period 2008–2010 averaged 26 t/ha less than the period from 1994–1998 (Table 4). The comparison between the two periods is complicated by the significant changes in varieties that have occurred since 2000. During 1994–1998 the region was dominated by Q124, with 89.2% area in the 2000 season.

Sugarcane variety Q124 out-performed other varieties, across most soil types, in the Mackay region. However, weather conditions during that period may also have been more favourable for cane production. The 1994–1998 period experienced, on average, 118 mm more effective rainfall, 682 mm lower total rainfall, better rainfall distribution, and likely lower incidence and severity of waterlogging than recently (2008–2010).

The difference in effective rainfall alone could account for ~ 10 t/ha using the total water use efficiency data described by Chapman (1997). Rudd and Chardon (1977) also showed that yield declined by 0.46 t/ha each day the water table was within 0.5 m of the soil surface during the peak growth period (Dec–June).


<table>
<thead>
<tr>
<th>Season</th>
<th>Yield</th>
<th>Average rainfall</th>
<th>Thermal time (cum. °D)</th>
<th>Solar radiation (cum. MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCH</td>
<td>TSH</td>
<td>Effective rain (mm)</td>
<td>Total rain (mm)</td>
</tr>
<tr>
<td>94–98</td>
<td>99</td>
<td>13.5</td>
<td>872</td>
<td>1218</td>
</tr>
<tr>
<td>05–07</td>
<td>86</td>
<td>11.4</td>
<td>865</td>
<td>1314</td>
</tr>
<tr>
<td>08–10</td>
<td>73</td>
<td>10.2</td>
<td>754</td>
<td>1900</td>
</tr>
</tbody>
</table>

Differences in temperature and solar radiation also favoured the 1994–1998 period, although only marginally. These data suggest that recent yields in the region have been affected by poor seasonal weather conditions. However, this is not to say that other factors have not contributed to the issue. The estimated seasonal weather conditions for the period from 2005–2007 were similar to those experienced in the mid 1990s (Table 4).

Although above average yields were produced, they were significantly lower than the mid 1990s period. This could be associated with a number of factors, with varieties, social, availability of labour, economic, etc. all likely contributors to the issue. These factors would also be present currently, but are perhaps not as apparent during periods of extreme weather.

If Q124 had not been affected by orange rust and was still being grown in the region currently, it would be possible to determine to what extent the high yields of the mid 1990s or the poor recent seasons were due to seasonal weather conditions. Unfortunately a comparison of Q124’s performance in recent years to its performance in the mid 1990s is not possible. However, sugarcane varieties Q135, Q136 and Q138 have been grown in the region since 1987.

The data suggest that despite the dominance of Q124 during the mid-1990s these other varieties were also performing well (Figure 2). The average performance of Q135, Q136 and Q138 was only 6% lower than Q124 during the mid-1990s. Currently (2008–2010) the average performance of these varieties is 36% lower than what it was in the mid-1990s. This suggests that either recent seasonal weather conditions were poor, some other factor(s) has changed over the period, or a combination of both.
Correlation between yield and seasonal weather conditions

A significant correlation (Equation 6) was found between cane yield and seasonal weather conditions (1990–2010).

Equation 6: Cane yield = 4.1 + 0.086 * effective rainfall – 0.02084 * total rainfall + 0.488 * % wet season, \(F(3,17) = 9.45, P < 0.001, R^2 = 0.559\)

The percentage of variation accounted for increased when the 2000 and 2001 seasons were excluded from the analysis (Equation 7). These seasons were affected by the outbreak of orange rust.

Equation 7: Cane yield = 165.5 + 0.0931 * effective rainfall – 0.01268 * total rainfall + 0.415 * % wet season – 0.0376 * thermal time + 0.334 * % effective rainfall, \(F(5,13) = 14.13, P < 0.001, R^2 = 0.785\) (Figure 3)
The correlation suggests that seasonal weather conditions have a significant bearing on crop yield in the Mackay region and provides further evidence that yields in recent seasons have been affected by seasonal weather conditions.

**Crop simulation**

APSIM simulated yields well in some seasons and poorly in others (Figure 4). It should be noted that the model is not generally used to simulate yields for an entire region and is more often used to simulate yields in specific experiments where site characteristics and crop inputs are known. Despite this, the model’s prediction for the mid 1990s period was greater than its prediction for recent seasons, which is consistent with observed yields in the region.

![Graph showing APSIM simulated yields and Mackay region actual yields for 1990–2010.](image)

The over-prediction of yield in seasons with high effective rainfall may be associated with difficulties simulating the effect of waterlogging. Often, seasons with high effective rainfall also have above average total rainfall (Table 3), leading to waterlogging on poorly drained soils.

No attempt was made to introduce code that reduced biomass growth during high rainfall periods in order to account for waterlogging. There were also other factors that the sugar module could not simulate without additional code.

Particularly the outbreak of orange rust in 2000 and increased harvester damage when conditions are wet. Both these issues affected the model’s ability to simulate yield from 1999–2001.

**Correlation over time (1950 –2010)**

It is more difficult to determine the effect of seasonal weather variability on sugarcane yield in the Mackay region over a longer period. This is because factors other than seasonal weather have changed significantly over the long term.

The period from 1950–2010 has seen very significant changes in the way sugarcane is farmed (fertilisers, herbicides, harvesting, irrigation, trash blanketing, mechanisation, etc.) and the varieties that are grown. These changes were associated with a period over which yield improved (Figure 5).
Correlations for 20-year rolling periods commencing in 1951 showed that the percentage variation in crop yield accounted for by rainfall parameters has increased over time (Figure 6). The variation explained was improved by the addition of the previous season’s yield as a predictor variable (yield history).

This was due to follow-on effects from one crop to another in the sugarcane system. Inclusion of some seasons, particularly 1991, had a large effect on the percentage variation explained.

Deleting 1991 from the analysis reduced the percentage variation explained but did not change the trend for an increasing correlation between yield and rainfall parameters with time. It would defeat the purpose to delete all years where climatic factors had a large effect on crop production.

Similar conclusions can be drawn from the analyses where residuals from a line of best fit were used as an indicator of crop variability over time (Figure 6).

An increasing correlation between yield in the Mackay region and rainfall parameters over time is not surprising. It could suggest that, in the past, factors other than weather were having a large effect on crop production.

Potentially, as crop management improved (nutrition, weed control, irrigation, etc) and better varieties were released, the effect of these factors declined, and variation in seasonal weather conditions had a greater influence on crop variability.

In addition to this, the Mackay region has expanded from ~ 20 000 ha in 1950 to 83 000 ha in 2000. This expansion would have occurred onto poorer soils where limitations due to low water holding capacity and potential for waterlogging were more likely.

These poorer soils can support good crops but, in terms of irrigation, they require frequent applications of low water volumes. Therefore, these soils are likely to be less productive in seasons with prolonged dry periods followed by intense rainfall events.
The Sugar Yield Decline Joint Venture (SYDJV) showed that soil condition has declined as a consequence of long-term sugarcane monoculture, excessive tillage practices and compaction (Garside and Bell, 2006). Soils with poor physical and biological properties have reduced infiltration, drainage and water holding capacity resulting in reduced cane growth.

However, to some extent these issues could be overcome in seasons when rainfall is well distributed and not excessive. Management that improves the condition of soil is important and recommendations from the SYDJV (break cropping, controlled traffic and minimum tillage) should form the basis for this approach.
Given that seasonal weather variability appears to be having an effect on crop production in the region, crop management approaches to reduce these effects need to be developed. Direct effects of poor or excessive rainfall can be managed by irrigation, where possible, and improved drainage systems. An economic analysis of the benefits of such work would need to be conducted at the farm and regional level.

The economics of investing in irrigation in the Mackay region has been evaluated previously and the outcome was dependant on whether the work was conducted in a wet or dry period (Chapman and Chardon, 1979; Chapman, 1997). However, water stress has had a significant effect on crop production in the Mackay region (Inman-Bamber et al., 2007).

Similarly, quantifying the effect of waterlogging at different stages of crop development and incorporating this information into crop models would be highly beneficial.

Variable seasonal weather conditions also influence the effectiveness of other management strategies. As an example, nitrogen fertiliser rates in the ‘Six Easy Steps’ program are based on yield potential (Schroeder et al., 2005, 2010). However, yield potentials could be adjusted, taking into account seasonal weather forecasts, timing of ratooning in relation to forecasts and various other possibilities.

There are risks associated with changing management strategies due to a weather forecast and we need to determine how often any suggested changes have beneficial outcomes. Nitrogen management is not the only practise that falls into this category, timing of nearly all operations could be manipulated after taking a seasonal forecast into account.

Climate change projections for the Mackay region include an overall reduction in total rainfall but increased intensity of events (Park, 2008). This outlook is not dissimilar to recent seasons with poor effective rainfall that also experience above average total rainfall. Currently these seasons produce below average crops (e.g. 2008).

Increases in regional temperature may provide some opportunities for managing seasonal conditions by allowing cane to be planted during the traditional cold periods. However, there are likely to be complex interactions between temperature, water relationships and other factors that lead to uncertainty in any outcome.

Either way, manipulation of farming systems and crop management to reduce the risk of seasonal weather variability needs further investigation.

Conclusions

- There has been considerable variation in sugarcane yield in the Mackay region over the last two decades (1990–2010)
- Variation in seasonal weather conditions appears to be a significant factor explaining this yield variation, but the importance of other non-weather related factors should not be over-looked (social, economic, availability of labour etc.)
- The seasonal weather conditions during the mid-1990s, when yields were well above average, appear to have been better than those experienced recently.
- Although Q124 dominated the Mackay region during this period, and performed well across a wide range of soil types, other varieties also performed better then, than they have done recently (Q135, Q136, Q138).
- Seasonal weather conditions appear to have had a greater influence on cane yield recently than in the past. This may be due to improved management and better adapted varieties reducing the effect of other non-weather related factors.
Managing seasonal weather variability requires more accurate forecasting tools and also well understood flexibility in sugarcane farming systems and crop management.

Opportunities to adapt crop management systems to cope with seasonal weather variability need to be identified, especially in light of climate change predictions.

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REFERENCES


