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Productivity performance of climatological sub-regions within the Tully Mill area

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Abstract Inter-annual climate variability has a significant impact on productivity in the Wet Tropics region. Climate also varies spatially, yet the impact on productivity is less well known. Two distinct climatological sub-regions (northern and southern) have been identified within the Tully mill area based on total annual rainfall and annual average daily radiation. The wetter northern sub-region is characterised by lower radiation, lower temperatures and higher rainfall than in the drier southern sub-region. Mean cane and sugar yields were analysed for the two climate sub-regions using block productivity data obtained from Tully Sugar Limited for 2000 to 2017. After excluding 2011 (Tropical Cyclone Yasi), only farms with 15 or more years of data were included. The impact of spring-summer (SONDJF) rainfall and El Niño Southern Oscillation (ENSO) phases on cane and sugar yields in the two climate sub-regions was also analysed. On average, the northern, wetter climate sub-region yielded less cane and sugar yield than the southern, drier sub-region. There were significant differences between SONDJF rainfall terciles (dry, normal and wet) and ENSO phases (El Niño, Neutral and La Niña) for cane and sugar yields in the two climate sub-regions. Cane and sugar yields were significantly lower in years experiencing high SONDJF rainfall or in the La Niña phase. This analysis validates the results of the analyses used to derive the two climatological sub-regions in Tully. Improved knowledge of how climatic conditions influence sub-regional productivity performance will assist industry extension programs and on-farm management decisions.

Key words Climate, productivity, extension, Tully

INTRODUCTION

Climatic conditions are known to impact sugarcane yields differently from year-to-year (Kuhnel 1994; Everingham and Reason 2011), among regions (Kingston 2000; Leslie and Wilson 1996; Everingham *et al.* 2015) and within mill areas (Sexton *et al.* 2017; Garside *et al.* 2014). Important consideration is given to the impact of climatic conditions on all growing, harvesting and milling operations when making management decisions. Recent research by Sexton *et al*. (2017) focused on identifying sub-regional 'climate zones' to help improve nitrogen fertilizer recommendations within the Tully Mill area. Seasonal and annual climate data from 1975-2017 were used in an analysis to determine sub-regional climatological differences. This resulted in the identification of two distinct climatological sub-regions in the Tully Mill area (Sexton *et al.* 2017), labelled as the *southern Dry* and *northern Wet* climate zones, and are roughly separated by the Tully River.

Improved knowledge of how climatic conditions influence sub-regional productivity within the Tully Mill area will assist industry extension programs and on-farm management decisions. In addition, this information may assist Tully Sugar Limited refine existing productivity zones to better represent productivity performance.

METHODS

Rake level productivity data for 2000 to 2017 were available from Tully Sugar Limited. Data pertaining to 2011 was omitted because of the extraordinarily wet growing season and subsequent impact of Tropical Cyclone Yasi.

Farms in the Kennedy subdistrict were also omitted, as productivity data were only available for six years with supply to Tully Sugar Limited commencing in 2011. This resulted in 221 farms having productivity data that met the above criteria.

The 2018 Tully Sugar spatial layer (F18) allowed the 221 farms to be allocated to the Wet or Dry climate zones (Figure 1). Using F18 to allocate farms to climate zones according to their spatial location instead of simply allocating farms based on productivity subdistricts (e.g. the Wet climate zone containing El Arish, Feluga, Syndicate and Lower Tully versus the Dry climate zone containing Riversdale, Euramo and Murray) resulted in the omission of another 15 farms from the analysis. These 15 farms had areas in both climate zones.

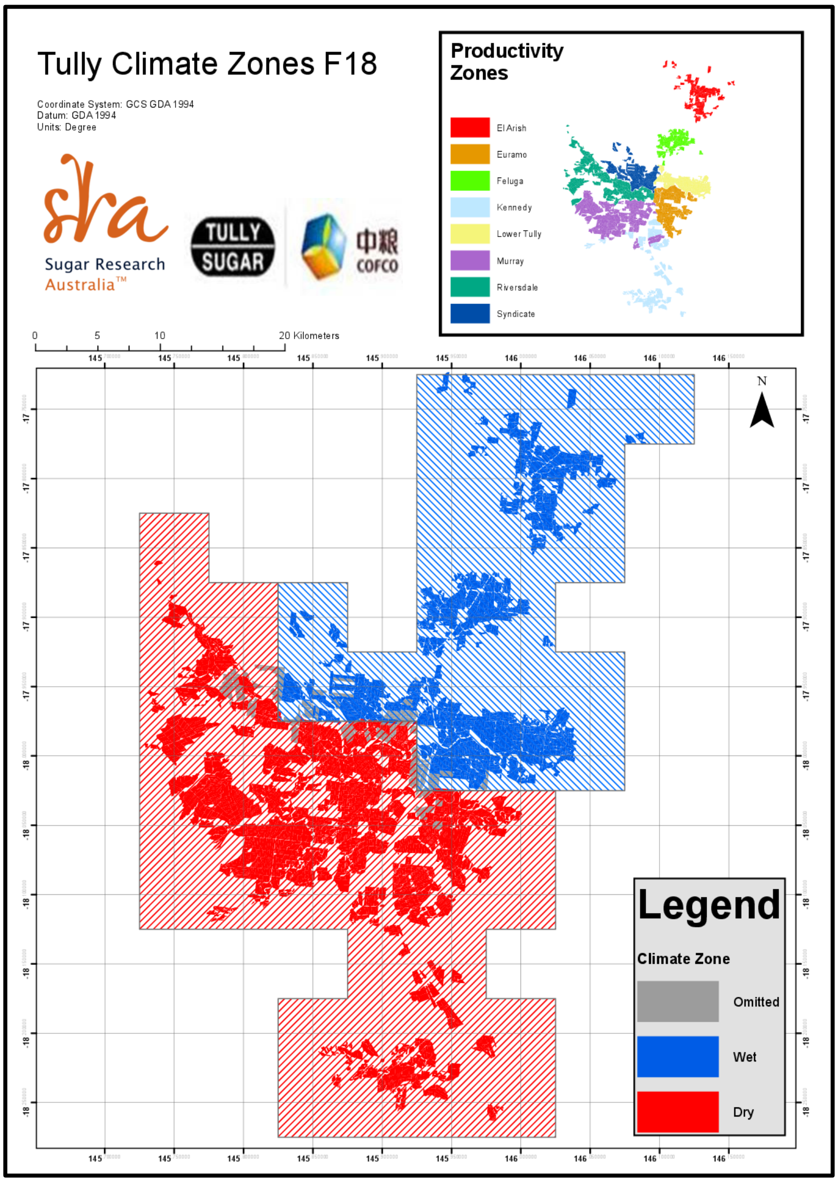

Figure 1. The Tully sugarcane milling area. Climate zones of Sexton et al. (2017) are superimposed on the eight subdistricts identified in the area. The map does not show the farms included/omitted from the analysis.

The impact of total spring-summer (SONDJF) rainfall on yields for the two climate zones was analysed given its strong influence on Tully cane yields (Skocaj and Everingham 2014). Years were categorised as being dry, normal or wet according to the methodology of Skocaj and Everingham (2014). In summary, their categorisation of total SONDJF rainfall for 1925 to 2016 resulted in dry years being defined as receiving less than or equal to 1604 mm of rainfall over spring-summer, wet years as receiving at least 2346 mm of rainfall, and remaining years as normal. The categorisation of dry, normal and wet years using total SONDJF rainfall was then associated with yields for the following harvest year. For example, total SONDJF rainfall experienced during 2014-2015 was ≤1604 mm so the 2015 yields were allocated into the dry years. For 1999/00 to 2014/15 there were six dry (pertaining to crops harvested in 2002, 2003, 2005, 2006, 2015, 2016), six normal (2004, 2008, 2010, 2013, 2014, 2017) and six wet (2000, 2001, 2007, 2009, 2011, 2012) years. However, as we omitted data pertaining to 2011, there were only five wet years included in the analysis.

Given the chance of experiencing high SONDJF rainfall increases when the El Niño-Southern Oscillation (ENSO) is in the La Niña phase, we also analysed the impact of ENSO phases on yields for the two climate zones. The Oceanic Niño Index (ONI) is a principal measure for monitoring, assessing and predicting ENSO phases (Smith and Reynolds 2003). ENSO phases were determined using the June to August (JJA) ONI the year before harvest. For example, the JJA ONI for 2014 were associated with yield for 2015. ENSO phases "El Niño", La Niña" and "Neutral" were defined as having ONI values greater than 0.5, less than -0.5, and between 0.5 and -0.5 (inclusive), respectively (Everingham 2007). The JJA ONI values for 1999 to 2014 were extracted on 28 February 2016 from the Climate Prediction Center website (http://www.cpc.ncep.noaa.gov). For 1999 to 2014 there were four El Niño (crops harvested in 2003, 2005, 2010, 2016), 11 neutral (2002, 2004, 2006, 2007, 2008, 2009, 2012, 2013, 2014, 2015, 2017), and three La Niña (2000, 2001, 2011) years. However, as we omitted data pertaining to 2011, there were only two La Niña years included in the analysis.

Boxplots were produced to determine the shift in the distribution of cane and sugar yields between the Wet and Dry climate zones. Boxplots were also produced to examine the shift in distribution of cane and sugar yields for the Wet and Dry climate zones for dry, normal and wet years (based on SONDJF rainfall) and La Niña, Neutral and El Niño phases (based on JJA ONI). All boxplots were produced using SAS Proc VBOX (SAS).

Kruskal Wallis non-parametric tests followed by Dunn's all pair-wise comparison statistical significance tests were used to test if SONDJF rainfall and ENSO phases had a significant impact on cane and sugar yields in the Wet and Dry climate zones. These analyses used Statistix 10 (Analytical Software).

RESULTS AND DISCUSSION

After excluding 2011, farms located in the Kennedy subdistrict and farms with areas in both climate zones, 206 farms had productivity data for all 17 years of the time series analysed (2000 to 2017). On average, the total area analysed each year from the 206 farms was 15,645 ha. The average area supplying Tully mill during this time was 24,912 ha (ranged from 20,306 in 2010 (standover) to 29,844 ha in 2017 (industry expansion)).

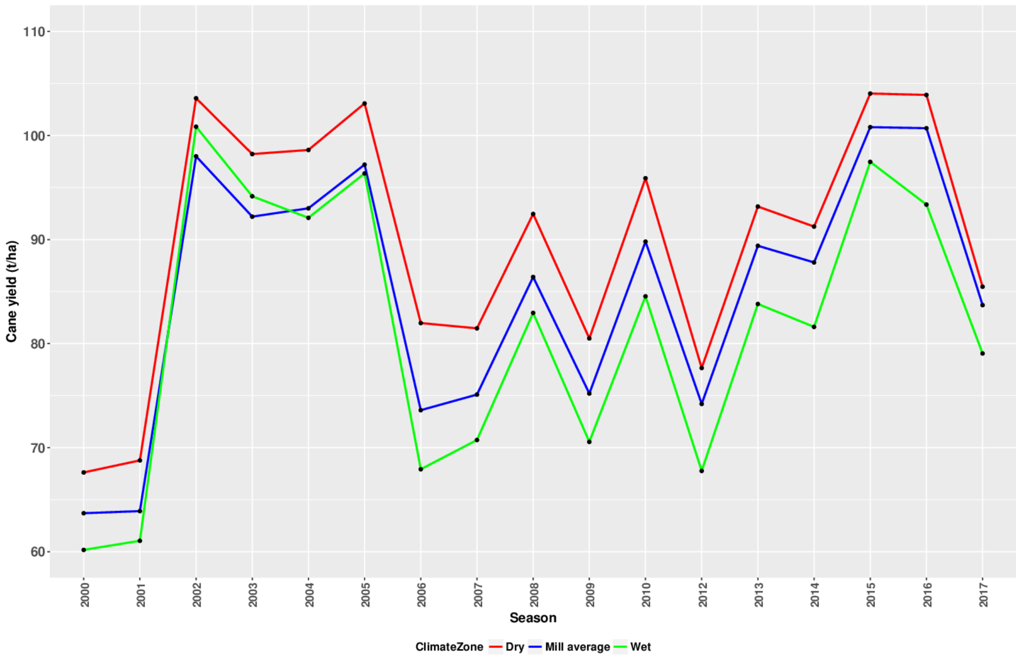

Figure 2. Mean annual cane yield (t cane/ha) for the Wet and Dry climate zones compared to Tully Mill mean annual cane yield for 2000-2017 (excluding 2011).

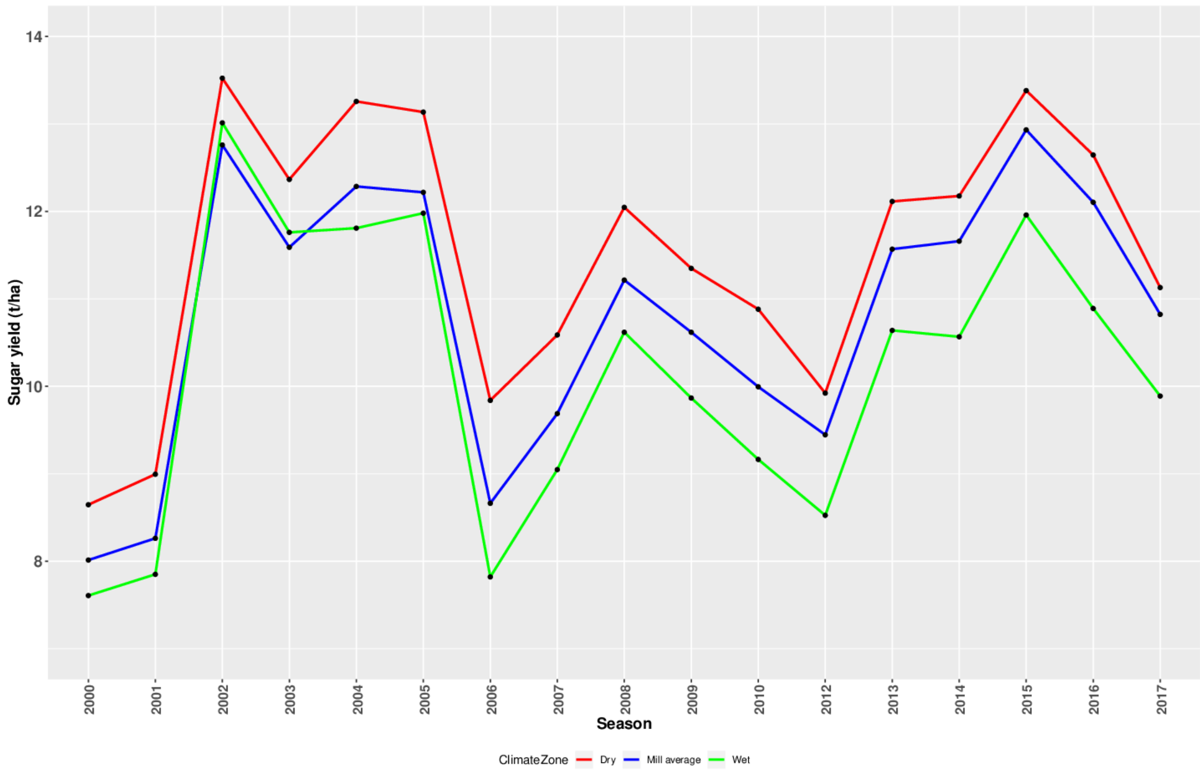

Figure 3. Mean annual sugar yield (t sugar/ha) for the Wet and Dry climate zones compared to Tully Mill mean annual sugar yield for 2000-2017 (excluding 2011).

The northern Wet climate zone always produced lower cane and sugar yields than the southern Dry climate zone ($p<0.001$) (Figures 2-3). The mean cane yield for the Wet climate zone over the 17 years analysed was 81.4 t cane/ha, whereas in the Dry climate zone it was 89.9 t cane/ha. The mean cane yield of the Tully Mill area (for all farms, not just those included in the climate zone productivity analysis) for these 17 years is 85 t cane/ha. Cane and sugar yields for the northern Wet climate zone were consistently lower than the Tully mill average, except in 2002 and 2003 where spring-summer rainfall was 936 and 797 mm, respectively.

This is well below the long-term Tully average and $\leq$1604mm threshold used to define dry years according to total spring-summer rainfall. However, in 2002 and 2003 the relativity of the Wet and Dry is still maintained but the mill average drops below both zones suggesting the performance of farms omitted from the analysis is the most important feature. For the northern Wet climate zone, crop growth is not constrained in years experiencing low spring-summer rainfall and, hence, environmental conditions are more conducive to producing these higher yields.

Cane and sugar yields differed among dry, normal and wet years (Figures 4-5). Spring-summer rainfall terciles had a significant effect on mean cane yields for both climate zones ($p<0.001$). The mean cane yield for wet years was significantly lower than dry and normal years for both climate zones. The mean cane yield for wet years was 66.1 t/ha and 75.2 t cane/ha for the Wet and Dry climate zones, respectively. In dry years the mean cane yields increased to 91.7 and 99.1 t cane/ha for the Wet and Dry climate zones, respectively.

Spring-summer rainfall terciles also had a significant effect on mean sugar yields for both climate zones ($p<0.001$). Mean sugar yields were significantly lower in wet years for both climate zones. The mean sugar yield for wet years was 8.6 and 9.9 t sugar/ha for the Wet and Dry climate zones, respectively, compared to 11.2 and 12.5 t sugar/ha in dry years.

Cane and sugar yields differed among El Niño, La Niña and Neutral ENSO phases (Figures 6-7). ENSO phase had a significant effect on mean cane yields for both climate zones ($p<0.001$). The mean cane yield in La Niña years was significantly lower than El Niño and neutral years for both climate zones. The mean cane yield for La Niña years was 60.6 t cane/ha and 68.2 t cane/ha for the Wet and Dry climate zones, respectively. In El Niño years the mean cane yields increased to 92.1 and 100.3 t cane/ha for the Wet and Dry climate zones, respectively.

ENSO phase also had a significant effect on mean sugar yields for both climate zones (p<0.001). Mean sugar yields were significantly lower in La Niña years for both climate zones. The mean sugar yield for La Niña years was 7.7 and 8.8 t sugar/ha for the Wet and Dry climate zones, respectively, compared to 11.0 and 12.3 t sugar/ha in El Niño years.

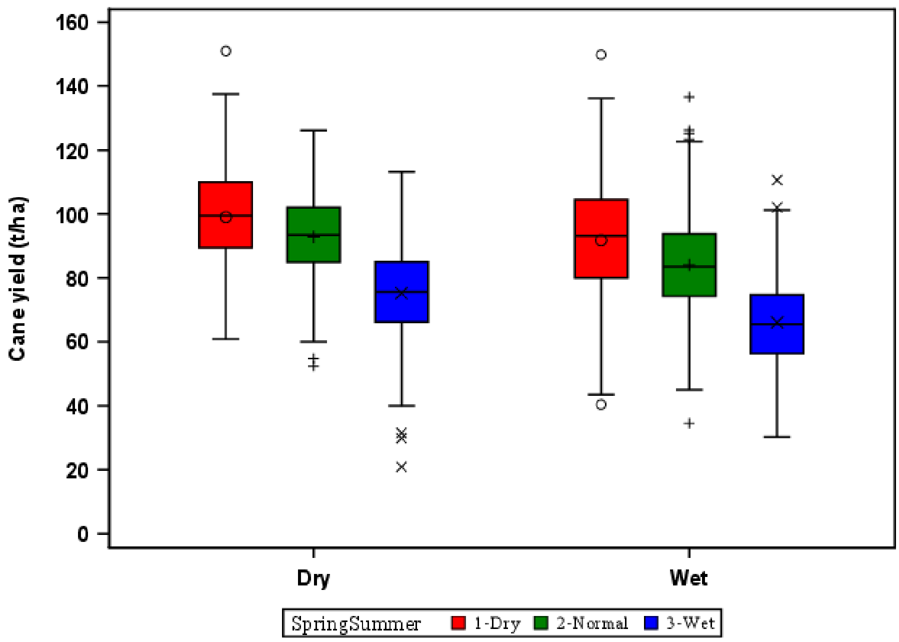

Figure 4. Shift in cane yield (t cane/ha) distribution between spring-summer terciles 1 (Dry), 2 (Normal) and 3 (Wet) for the Dry and Wet climate zones for 2000-2017 (excluding 2011).

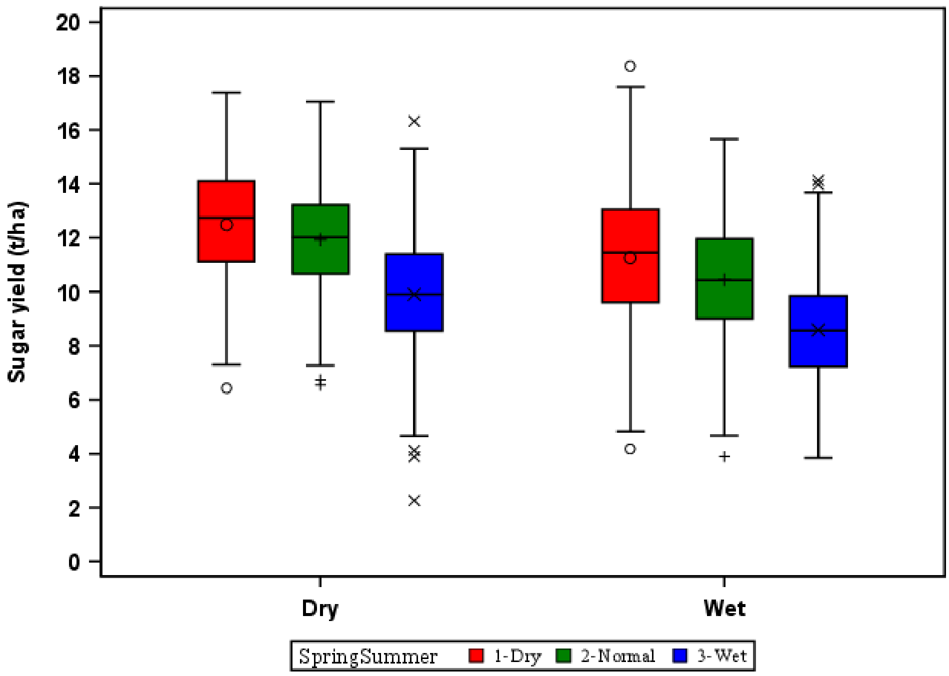

Figure 5. Shift in sugar yield (t sugar/ha) distribution between spring-summer terciles 1 (Dry), 2 (Normal) and 3 (Wet) for the Dry and Wet climate zones for 2000–2017 (excluding 2011).

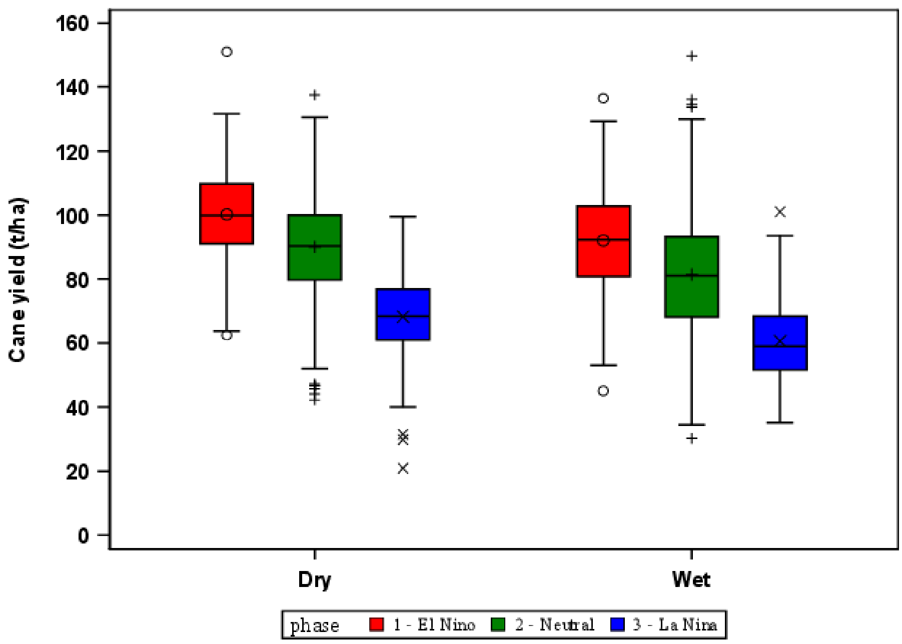

Figure 6. Shift in cane yield (t cane/ha) distribution between ENSO phase El Niño, Neutral and La Niña for the Dry and Wet climate zones for 2000-2017 (excluding 2011).

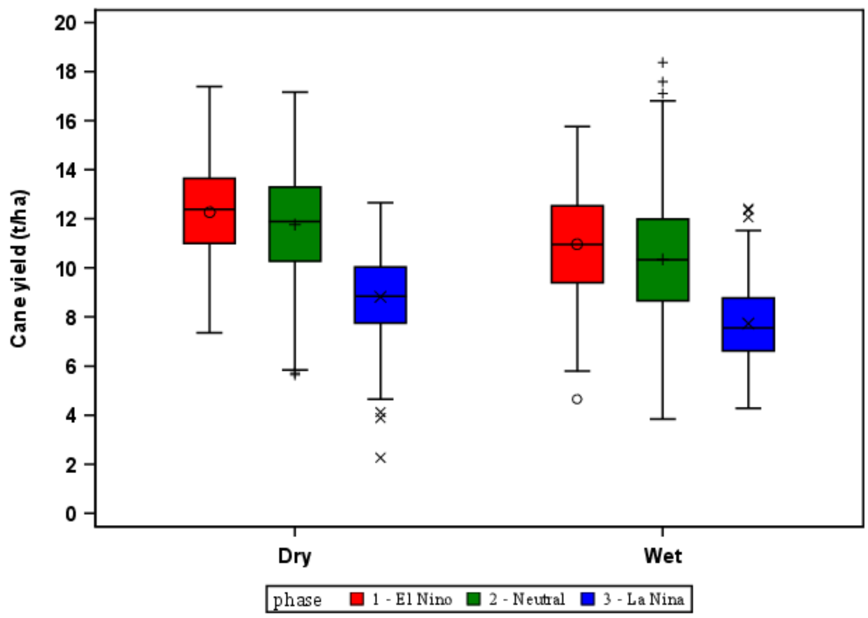

Figure 7. Shift in sugar yield (t cane/ha) distribution between ENSO phase El Niño, Neutral and La Niña for the Dry and Wet climate zones for 2000-2017 (excluding 2011).

Given the low sample size (n=2) of La Niña years (1999/2000 and 2000/2001) included in the 17-year time period analysed it is important to remember that not all La Niña events will have the same impact on yields. No two La Niña (or El Niño) events are the same (differences in rainfall quantity and distribution), so the impact on crop growth and yields can be different. The La Niña events of 1999/2000 and 2000/2001 were extreme and resulted in high rainfall, prolonged waterlogging, harvesting difficulties and standover across many regions of the Australian sugar industry (Everingham *et al.* 2001).

Located in the Wet Tropics, the Tully Mill area is characterised by extreme inter-annual climate variability, high rainfall, excessive soil wetness, reduced solar radiation and flooding events. Therefore, it is not surprising cane and sugar yields are lower in growing seasons experiencing high spring-summer rainfall or a La Niña event as these conditions are exacerbated. High spring-summer rainfall results in persistent waterlogging and water inundation due to more frequent flooding events and lower solar radiation. In contrast, for years where the growing season experiences low spring-summer rainfall or an El Niño event, yields increase because these constraints on crop growth are less severe.

CONCLUSIONS

There were significant differences between spring-summer rainfall terciles (dry, normal and wet) and ENSO phases (El Niño, Neutral and La Niña) for both cane and sugar yields in the two Tully climate sub-regions. Cane and sugar yields were significantly lower in years experiencing high spring-summer rainfall or in the La Niña phase. Yields significantly increased as the amount of spring-summer rainfall decreased. However, despite categorising years according to the total amount of spring-summer rainfall recorded, it is important to remember the distribution of spring-summer rainfall will also affect yields. Hence, despite years being categorised as dry, normal or wet, yields for individual years within these categories will differ owing to differences in the amount and distribution of rainfall received at different crop stages. Our analysis has focused on the overall impact of spring-summer rainfall and ENSO phases on mean yields for 2000 to 2017 instead of the variation in yields for individual events (e.g. dry years of La Niña years).

Everingham *et al.* (2003) first established a link between ENSO and cane yields in the Tully mill area. They found cane yields tended to be above average in El Niño years and below average in La Niña years. This productivity analysis has built on the research conducted by Everingham *et al.* (2003), Skocaj and Everingham (2014) and Sexton *et al.* (2017) to improve the understanding of how different climatic conditions affect cane and sugar yields for the different climate zones in the Tully mill area. However, it is important to remember not all La Niña (or El Niño) events, wet or dry years are the same and yields will differ for individual events because of differences in rainfall intensity and duration.

Improved knowledge of how climatic conditions influence sub-regional productivity performance will assist industry extension programs and on-farm management decisions. For example, in the northern Wet climate zone in a wet year, growers may place greater urgency around applying fertiliser and pesticides before the onset of the wet season when the JJA ONI is in the La Niña phase. In addition, the Tully sugar industry may also be able to refine existing productivity zones to better represent productivity performance across the region.

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