REFEREED PAPER

YIELD ANALYSIS IN THE WEST SECTOR OF THE MAURITIAN SUGARCANE INDUSTRY

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Abstract

The Mauritian sugarcane industry has witnessed a declining trend in sugar productivity since 2001. A study was therefore implemented to investigate the impact of climate on cane productivity. The study was carried out on a sector basis. This paper reports the outcome for the West Sector, of which approximately 4000 ha are corporately managed, with nearly 90% under irrigation.

The locally validated sugarcane module of the Decision Support System for Agro-Technology Transfer (DSSAT) v3.5 was adopted to simulate the climatically determined yield for the period 1998 to 2007 at one site using the crop coefficient of variety R 570 grown in a 120 cm deep soil with a total available water content of 142 mm under both rainfed and non-limiting water conditions. A 12-month ratoon harvested on 01 October was adopted as representative of the harvest season (July to November).

Climatically determined cane yield (1998-2007) averaged 20 t/ha under rainfed conditions and 142 t/ha under fully irrigated conditions, with high correlation with solar radiation (r^2=0.778) in the latter case. Recorded irrigated yields averaged 99.9 t/ha at the La Mecque Section and the trend in the recorded yields was similar to the simulated fully irrigated yields. In line with previous observations, evapotranspiration use efficiency averaged 8.1 mm/t cane (7.9 to 8.3 mm/t cane) under fully irrigated conditions. Irrigation explained 86% of the climatically determined yield, and variations in recorded yields were largely explained by the irrigation level adopted. Record yield attained only 70% of the climatically determined yield, with 50% of the yield gap being attributed to constraints in irrigation and the remainder attributed to other management constraints.

Keywords: sugarcane, yield decline, simulation modeling, DSSAT-Sugarcane, irrigation

Introduction

The sugarcane industry of Mauritius (57.5°E and 20.5°S) extends over 70 000 ha, of which about two-thirds is corporately managed. The West Sector has witnessed a declining trend in sugar productivity attributable to both lower cane yields and lower extraction rates since the 2001 crop. This sector had previously recorded the fourth best sugar production since 1953. While increasing adoption of mechanisation and less stringent management as a consequence of staff reductions may be partially responsible for this decline, the large reduction in observed yield remains a serious concern. In some cases, the magnitude of loss in productivity has been higher than in 2002, when the severe tropical cyclone *Dina* passed at 50 km off the coast of Mauritius.

Sugarcane and sugar productivity are heavily dependent on the management practices adopted and the prevailing weather. A study was therefore implemented to assess the impact of the combination of the prevailing weather and the adopted management options on sugarcane yield. Given that the sugarcane industry extends over a range of agro-climatic conditions, the industry is divided into five contrasting sectors, namely the East, South, Centre, North and West Sectors. Each sector is characterised by a variation in altitude, weather regimes and soil types. The sectors are further divided into sections, and this study was conducted at section level. This paper presents the study for the West Sector.

The West Sector lies on the leeward side of the island and sugarcane is grown on a range of soil types situated from sea level to an altitude of 275 m above sea level. The rainfall averages 1125 mm per year (750-1500 mm per year) and mean temperatures of 27 °C in January and 21 °C in July are experienced (MSIRI, 2008). At the weather station with long-term records (Medine), annual rainfall averages 761 mm and solar radiation amounts to 6512 MJ/m. The area cultivated with sugarcane in the West Sector extends over 5600 ha, with approximately 4000 ha owned by the corporate sector, where crop management falls under the supervision of a qualified agronomist (MSIRI, 2008). In the latter case, agronomic management (varietal choice, cropping cycle, pest and weed control and irrigation) is expected to be close to optimum. Supplementary irrigation is applied to nearly the whole area under corporate management, i.e. 3585 ha in 2007 (MSIRI, 2008). The corporate sector is divided into six sections, where agro-climatic conditions and adopted management options are contrasting (Figure 1). One section, Bassin, was merged into the adjoining sections of Beaux Songes and Henrietta in 2005.

Methodology

Data on cane yield, planting pattern and percentage area under different genotypes for the period 1998 to 2007 were extracted from the MSIRI Land Index Database. The data were summarised and trend analysis was performed.

The previously calibrated and validated sugarcane module of the Decision Support System for Agro-Technology Transfer (DSSAT) v3.5 (Cheeroo-Nayamuth and Nayamuth, 2002, Cheeroo-Nayamuth *et al.*, 2002) was used for the study to integrate the combined impact of climatic parameters on cane yield, soil parameters and management practices. The evapotranspiration (ET) demand and the climatically determined yields for 1998 to 2007 were simulated using the crop coefficient of variety R 570 grown in a 120 cm deep soil with a total available water content of 142 mm under rainfed conditions. A 12-month ratoon harvested on 01 October was adopted as representative of the local harvest season that extends from July to November. The potential loss of yield accountable to sub-optimal irrigation schedules was assessed using the automatic irrigation option of the model. It was assumed that decision-making would have been efficient, i.e. genotype, weed control, nutrient inputs and management would be at the optimum level. Thus, the exercise did not consider yields constrained by nutrients or weed management.

The ET was computed after accounting for runoff, deep drainage and the residual amount of water in the soil profile of a field with a slope of 5%. The ET under rainfed conditions was compared to that required in the absence of water stress; the wider the difference between the two, the larger the expected shortfall in yield.

Since detailed long-term weather data were available only from the Medine weather station, the exercise was conducted at this site. In order to avoid the confounding factor of spatial climate variability, simulated data were compared with those from one adjoining section, namely La Mecque (Figure 1).

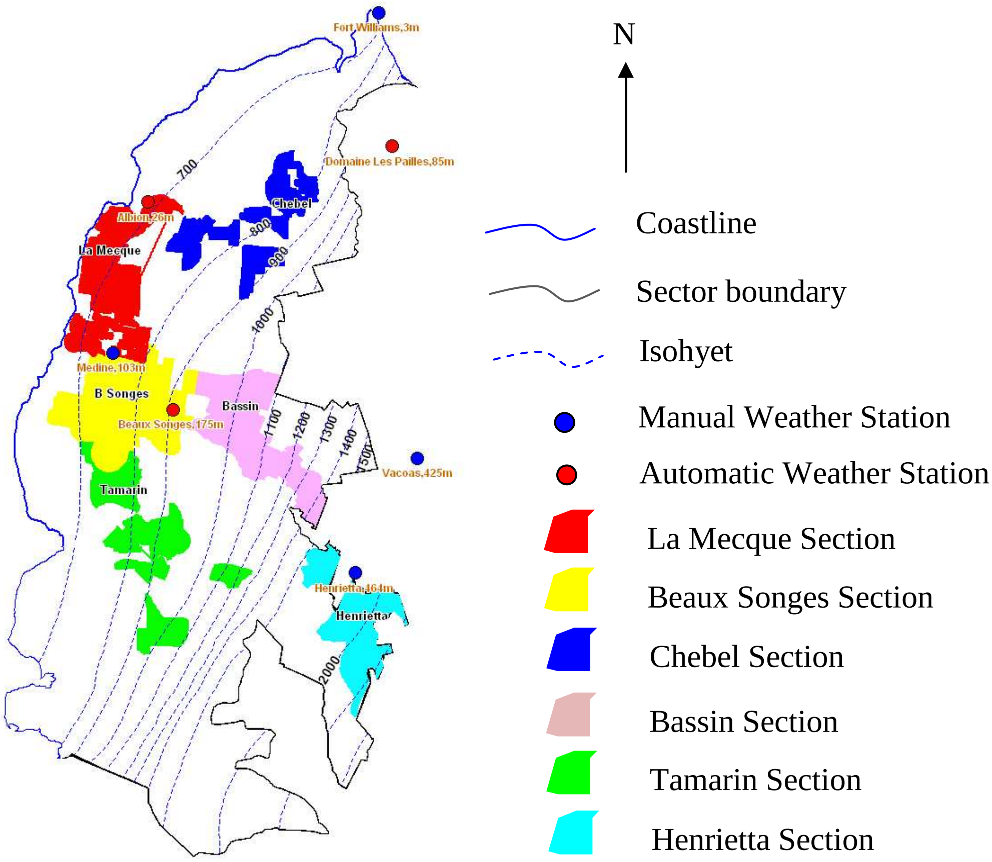

Figure 1. Estate sections, isohyets and selected weather stations in the West Sector.

Results and Discussion

Period under study

The study was conducted from 1998 to 2007. The characterisation of these years by the Sugar Insurance Fund Board (SIFB, 2008) is shown in Table 1. With the exception of year 2004, the SIFB has declared all years as event years for compensation purposes. However, the intensity and duration of the 'weather events' were of different degrees of importance. Additionally, the declaration of an event year by the SIFB for compensation purposes is not strictly related to the weather, but includes yields achieved in comparison with the best three years of the last twelve years. Thus, other factors that may have been responsible for the yield reductions are automatically included along with any climatic impact.

For the study, the year 2001 was considered a good year with near-potential cane and sugar productivity. The shortfall in production amounted to only 5% at Island level when compared to the insurable sugar (SIFB, 2008) and it was thus adopted as the reference year for the assessment. For the West Sector, production in 2001 exceeded the benchmark by 3%. It was expected that the major part in the fall in productivity of year 2002, reported as 15% by SIFB (2008), would be attributable to the impacts of cyclone *Dina*. Cyclones *Gerry* and *Manou* in 2003 were of lower intensity and passed quite far from Mauritius and it was expected that their impacts on productivity would be small.

Table 1. Characteristics of years (1998-2007) under study for Medine site.

Year	CYCLONE						SIFB EVENT *	
	Name	**Date**	**Intensity**	**Closest distance (km)**	**Maximum gust (km/h)**	**Associated rainfall (mm)**	**Event**	**% production**
1998	*Anacelle*	10-11 Feb	Cyclone	60, E	93	71	D	
1999	*Davina*	8-10 Mar	Cyclone (166-173 km/h)	25, SE	125	87	**C, D (50% mean rain)**	**38**
2000							D	84
2001							D	103
2002	*Dina*	20-22 Jan	Very intense cyclone (213-253 km/h)	50, N	169	481	C, E	85
2003	*Gerry*	10-13 Feb	Cyclone (118-167 km/h)	100, NNE	113	25	D	93
	Manou	4 May	Moderate storm (61-87 km/h)	350, NNE	108	33		
2004							No Event	99.6
2005							D, E	99.9
2006	*Diwa*	3-5 Mar	Moderate storm (61-87 km/h)	235, W	112	82	D, E	92
2007	*Gamede*	24-25 Feb	Intense cyclone (168-212 km/h)	220, NW	158	89	C, D, E	90

*C = Cyclone, D = Drought, E = Excessive rainfall

Weather for the period 1998 to 2007 at Medine in the West Sector

Compared to the long-term annual rainfall (761 mm) and solar radiation (6512 MJ/m), the amounts received in the reference year (2001) for both parameters was lower. Rainfall was 95 mm lower in 2001 and solar radiation 253 MJ/m lower (Table 2).

During the study period, three seasons drastically contrasted from the reference year (Figure 2). The year 1999 was characterised by a severe drought receiving only 309 mm of rainfall (40% of the long-term annual rainfall), and years 2002 and 2005 received above average rainfall of 1058 mm and 1075 mm respectively (Figure 2a). In 2002, the excess rainfall was primarily associated with a cyclonic episode of a couple of days and associated with 481 mm of rain. In 2005, the excess rainfall was associated with six heavy rainfall events of more than 60 mm each over the period December 2004 to

February 2005. The distribution of solar radiation was more even than for the rainfall parameter (Figure 2b). With the exception of 2003 when the seasonal solar radiation was only 5980 MJ/m, solar radiation received exceeded that of the reference year during the study period, reaching even 6712 MJ/m in 2006.

Table 2. Seasonal rainfall, irrigation and evapotranspiration at Medine (soil depth = 120 cm).

Year	Solar radiation (MJ/m^2)	Rainfed		Irrigated		ET deficit (mm)
		Rainfall (mm)	ET (mm)	Irrigation (mm)	ET (mm)	
1998	6479	670	481	949	1180	699
1999	6594	309	358	1049	1210	852
2000	6440	725	379	954	1152	773
2001	6259	666	564	861	1145	581
2002	6386	1058	519	907	1129	610
2003	5980	675	505	844	1061	556
2004	6488	727	556	880	1153	597
2005	6488	1075	534	920	1157	623
2006	6712	531	392	1075	1198	806
2007	6371	626	401	994	1161	760
Average	6420	706	469	943	1155	686

The combined effect of rainfall distribution and solar radiation was assessed through the seasonal ET deficit, i.e. the difference between ET under rainfed conditions and ET under fully irrigated conditions (Figure 2c). The lowest ET deficit was simulated in season 2003 (556 mm) and it corresponded with the lowest seasonal solar radiation of the period. The ET deficit for the reference season amounted to 581 mm and was exceeded in all other seasons with the exception of year 2003. The highest ET deficit (852 mm) was simulated in season 1999.

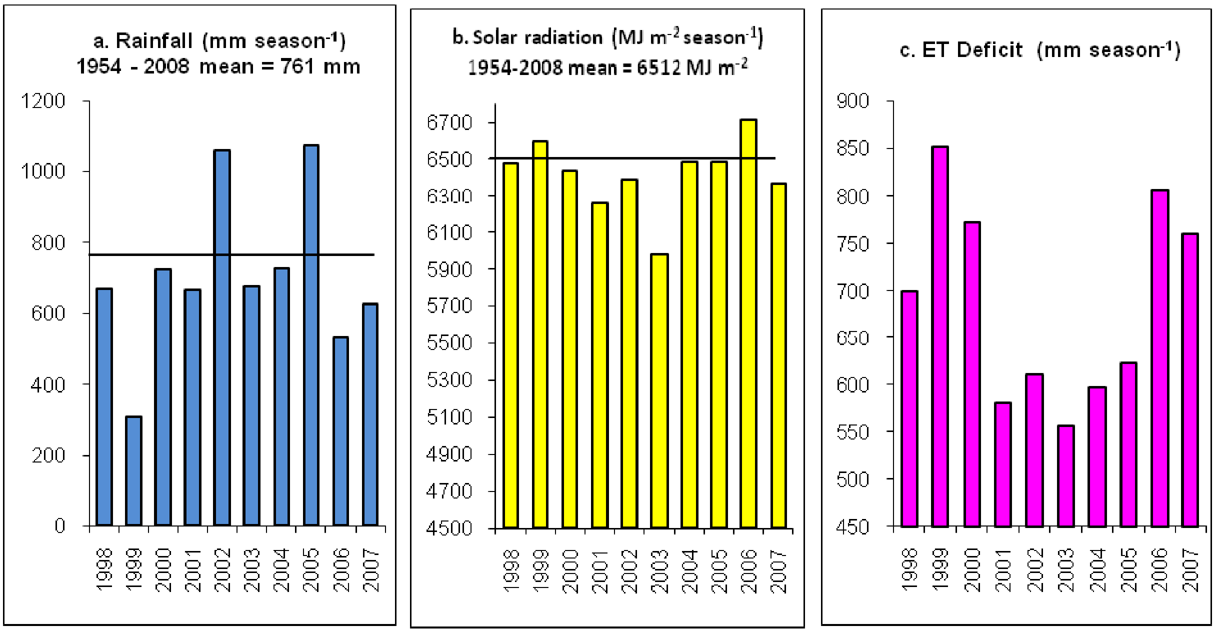

Figure 2. Seasonal rainfall, solar radiation and evapotranspiration deficit at Medine.

Simulated yield at Medine and recorded yield at adjoining La Mecque Section
Over the study period, the simulated rainfed yield ranged from 3.6 t/ha in 1999 to 42.9 t/ha in 2004 with an average of 19.7 t/ha and the simulated fully irrigated (climatically determined) yield ranged from 129.9 to 148.9 t/ha with an average of 142.3 t/ha (Table 3). These results were in line with simulation results using the APSIM-Sugarcane Model at Medine (Cheeroo-Nayamuth *et al*., 2000) and the DSSAT-Sugarcane Model at Tamarin in the West Sector (Cheeroo-Nayamuth and Nayamuth, 2002). The very low rainfed yield of 1999 was attributed to the very low rainfall, which was 40% of the long-term annual rainfall received over that season. The rainfed yield of year 2000 amounted only to 4.6 t/ha despite the fact that the recorded rainfall was more than double the 1999 amount (Table 2). The low yield was attributed to the poor distribution of rainfall (274 dry days, nine rainfall events of >10 mm and four rainfall events of >50 mm) and the unavailability of irrigation to meet the high ET deficit of 773 mm for that year. The simulated fully irrigated yield in the reference year of 2001 amounted to 141 t/ha and that yield was exceeded over the period 2004 to 2007 with the highest yield being simulated in 2006. Thus, if management adopted was at optimum level, yield trend over the period would exhibit an increasing trend.

The simulated yield gain from irrigation ranged from 99.1 t/ha (76% of climatically determined yield) in a good year to 142 t/ha (98% of climatically determined yield) in an extremely dry year. Irrigation, on average, explained 86% of the climatically determined yield over the study period and inclusive of the two extreme years (1999 and 2000). Thus, irrigation is confirmed as the main yield determinant in the West Sector.

The simulations indicated that on average approximately 943 mm of water would have had to be applied at specific times to ensure that the ET demand was met to achieve the average yield gain of 122.6 t/ha. The ET use efficiency under fully irrigated conditions averaged 8.1 mm/t cane and were similar to the outcome of previous simulation studies (Cheeroo-Nayamuth and Nayamuth, 1999).

Simulated cane yield under fully irrigated conditions increased linearly with solar radiation with a correlation coefficient of 0.7784 (Figure 3). Under rainfed conditions, cane yield decreased with increasing solar radiation, but with a lower correlation coefficient (R^2=0.1733). The lower correlation between cane yield and solar radiation in the latter case was due to the effect of year-to-year variation in rainfall distribution.

Recorded yield at La Mecque, the Section that is adjacent to the Medine weather station, ranged between 57.1 t/ha in 1999 to 114.8 t/ha in 2005, with an average of 99.9 t/ha (Table 3). Thus, the difference between attainable yield and climatically determined yield for the La Mecque Section was 42.4 t/ha, a gap of 30%. Of the 30% difference between the recorded and the climatically determined yield, 16% (86% minus 70%) was attributed to the inability to meet the total ET demand of the crop and the remaining 14% was attributed to constraints in other management practices. The latter could include factors that are not simulated by the model, such as the inability to completely adhere to the optimum cycle for genotypes with specific ripening behaviour, partial deterioration due to the development of pith in genotypes with intense flowering behaviour, and impacts of competition from pests, diseases and weeds, amongst others.

Table 3. Recorded yield at La Mecque Section and simulated yield at Medine.

Year	Recorded cane yield (t/ha)	Simulated cane yield (t/ha)		
		Rainfed	Irrigated	Gain from irrigation
1998	101.0	13.6	142.5	128.9
1999	57.1	3.6	146.4	142.8
2000	86.9	4.6	140.8	136.2
2001	110.1	34.9	140.9	106.0
2002	100.6	13.9	137.4	123.6
2003	105.9	30.8	129.9	99.1
2004	112.1	42.9	145.2	102.4
2005	114.8	29.7	144.7	115.0
2006	108.4	12.0	148.9	136.9
2007	102.3	10.6	146.3	135.7
Average	99.9	19.7	142.3	122.6

Recorded yields were closer to the irrigated climatically determined yield rather than the rainfed yield, confirming the key role of irrigation as a yield determining factor in the West sector. The relationship between recorded yield and solar radiation closely resembled the relationship between the latter parameter and simulated yield (Figure 3). However, the slope of the trend line was lower for the recorded yield (0.0043) compared to 0.0246 under simulated fully irrigated conditions, resulting in a widening of the gap between recorded and climatically determined yield with increasing solar radiation. Increasing solar radiation is generally associated with a higher energy load leading to higher ET demands. Additionally, Koonjah *et al.* (2011) reported that for every increase of 49 MJ/m per year the annual rainfall decreases by 100 mm in the West Sector. Thus, increasing solar radiation is also associated with drier years and with further restrictions on water availability for irrigation leading to yield reductions.

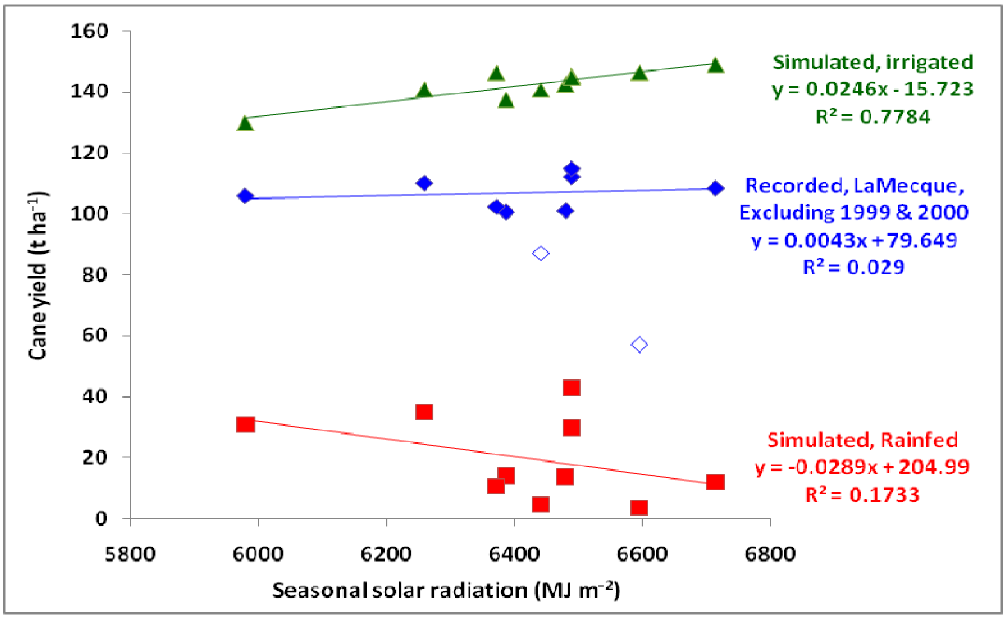

Figure 3. Regression of cane yield on seasonal solar radiation.

Recorded cane yield on sections in the West Sector

The average yield, inclusive of the yields from the extreme years, at sector level over the period 1998 to 2007 amounted to 81.3 t/ha and the highest yield of 91.5 t/ha was recorded in 2001 (Table 4). Among the different sections, La Mecque obtained the highest yield (99.9 t/ha) followed by Beaux Songes (85.5 t/ha), Chebel (85.2 t/ha) Tamarin (79.0 t/ha), Henrietta (70.3 t/ha) and Bassin (63.9 t/ha). Thus, attainable yield potential at section level generally decreased with decreasing amounts of solar radiation.

Table 4. Solar radiation and recorded cane yield in different sections in the West Sector.

	Section name						**Sector average**
	La Mecque	**B Songes**	**Chebel**	**Tamarin**	**Bassin**	**Henrietta**	
Solar radiation* (MJ/m/ d)	18.0	17.5	18.0	16.5	17.0	16.0	
Rainfall* (mm per year)	776	911	933		1251	1878	
1998	101.0	86.3	88.2	89.1	69.3	76.0	85.0
1999	57.1	35.4	35.8	49.9	36.2	67.9	47.0
2000	86.9	74.5	83.9	83.2	54.8	72.5	76.0
2001	110.1	95.4	103.0	93.3	71.0	76.4	91.5
2002	100.6	85.0	90.3	73.7	64.8	68.1	80.4
2003	105.9	96.5	91.8	81.6	73.6	76.9	87.7
2004	112.1	101.6	96.6	78.1	72.5	71.2	88.7
2005	114.8	103.1	88.4	85.9	69.1	73.6	89.2
2006	108.4	89.3	89.6	78.1	Merged with adjacent sections	61.4	85.4
2007	102.3	88.2	84.3	77.3		58.7	82.2
Average	99.9	85.5	85.2	79.0	63.9	70.3	81.3

*1951 to 1980 average (Padya, 1984)

The time trend in the simulated fully irrigated yield was characterised by a fairly stable trend with the exception of year 2003 when slightly lower yields were observed. This could be explained by relatively lower amounts of solar radiation (5980 MJ/m^2 per season) compared to the long-term average of 6512 MJ/m^2 per season (Figure 4). With the exception of the Henrietta Section, the trends in the recorded yields were similar in the five remaining sections, with the lowest yields being attained in 1999 due to severe drought that prevailed during that year. No decline was simulated in years 2006 and 2007.

While the simulated rainfed yield reached only 4.5 t/ha in 2000 (Table 3 and Figure 4), recorded yields attained about the midpoint between the lowest and average yield of the particular sections and this improvement was attributed to the adoption of irrigation. The next drop in recorded yield was recorded in 2002, a cyclonic year associated with excessive rainfall of 481 mm (Table 1) over a couple of days with the balance of rainfall over the remaining year being lower than the long-term average rainfall. The dip in the yield records for that year was attributed to an inability to meet ET demands due to restrictions in the availability of water. Recorded yields in 2006 and 2007 exhibited a declining trend. These two years were characterised by low rainfall, high solar radiation and high ET deficits with magnitudes resembling those in years 1999 and 2000 (Table 2). It is highly probable that in years 2006 and to a slightly lesser extent in 2007, water was available to partly meet the ET demand in such a way that yield depressions were not as severe as in 1999 and 2000.

The quantum of recorded yield depression in 2006 and 2007 at Henrietta and Beaux Songes was higher than at la Mecque, Chebel and Tamarin sections (Table 4 and Figure 4). The higher magnitude of decrease was attributed to the negative impact of merging of lower yielding fields from basin Section into Beaux Songes and Henrietta Section.

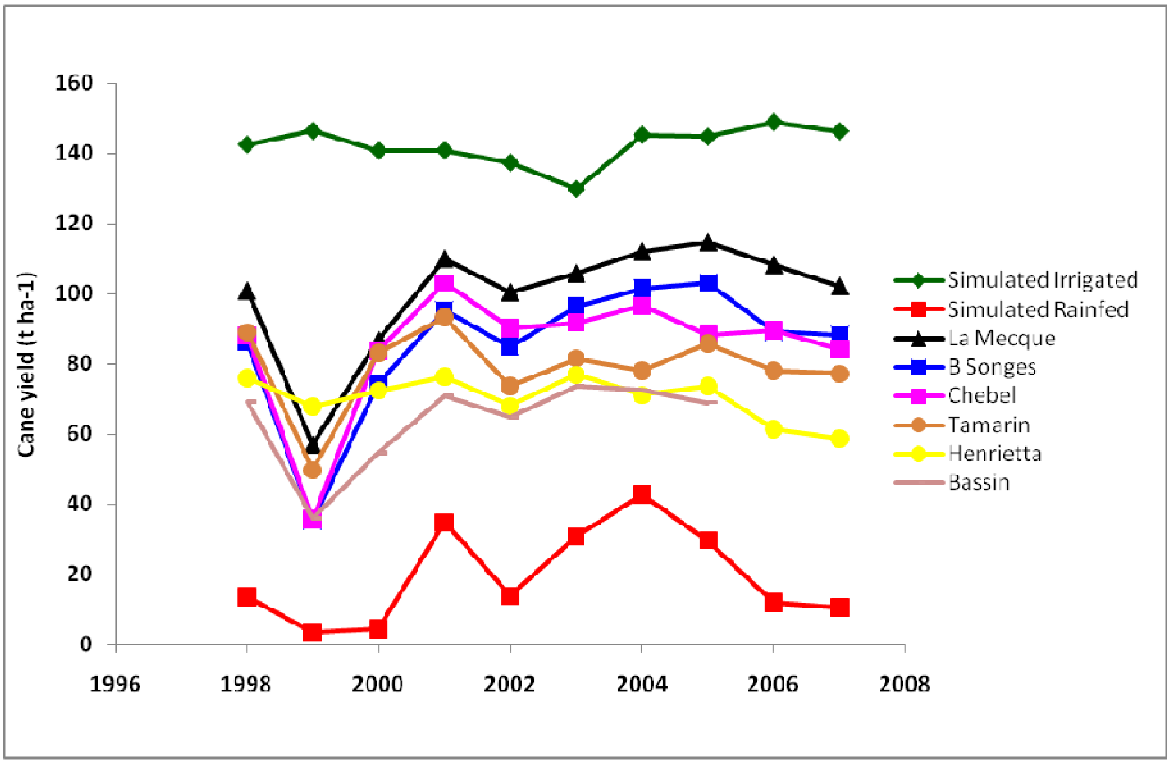

Figure 4. Recorded sugarcane yield in sections of the West Sector.

Conclusions

The period of study, 1998 to 2007, was characterised by two dry years (1999 and 2000) when cane yield was severely limited and two equally dry years (2006 and 2007) when yields were not as severely constrained. Simulation studies using the DSSAT-Sugarcane Model could be performed at a single site where detailed weather data were available. Simulated rainfed cane yield averaged 20 t/ha while the climatically determined yield, simulated using the auto-irrigation option of the model, amounted to 142 t/ha over the study period. Irrigation thus explained 86% of the climatically determined yield and was therefore identified as the main yield-determining factor for the particular site. Under non-limiting water conditions, cane yield was positively correlated with solar radiation. Average recorded yield, inclusive of the two extreme years at an adjoining section (La Mecque) was 100 t/ha, equivalent to 70% of the climatically determined yield. Of the 30% difference between the recorded and the climatically determined yield, 16% (86% minus 70%) was attributed to the inability to meet the total ET demand of the crop and the remaining 14% was attributed to constraints in other management practices. The latter could include the inability to completely adhere to the optimum cycle for genotypes with specific ripening behaviour, partial deterioration due to the development of pith in genotypes with intense flowering behaviour, and the impact of competition from pests, diseases and weeds, amongst others.

Recorded yield trends closely followed that of climatically determined yield, with the yield gap increasing with increasing seasonal solar radiation amounts. Departures were attributed to constraints in irrigation in four sections. Yield depressions observed at Henrietta, where only rainfed production is practiced, were attributed in 2006 and 2007 to the impact of merging of fields from a section with lower yield potential.

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