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INVESTIGATION INTO THE HIGH SUCROSE YIELD IN THE 2005 SEASON AT NAKAMBALA, ZAMBIA

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Abstract

Nakambala is an irrigated estate situated in the southern province of Zambia. The highest recorded yield on the estate was 18.2 tons sucrose per hectare per annum (TSHA) in 2005, resulting primarily from increased biomass yield (12% increase in tons cane per hectare per annum compared to the five year average over 2000-2004. The 2005 climate data was interrogated and employees were interviewed to find clues to the high yield.

The climate data showed that the high yield was produced under drought conditions in the presence of adequate water for irrigation. The rainfall was 55% of the long term mean (LTM) and the number of rain days was 63% of LTM, with average relative humidity at 58%. The high cane and sucrose yields were driven by high average daily sunshine hours of 9.4 hours (107% of LTM), high average maximum temperature of 30.3°C (104% of LTM) and average temperature range of 14.3°C (107% of LTM). total radiation was 8668 MJ/m²/annum, representing 104% of the LTM. The data indicates that a combination of high temperatures, wide diurnal temperature fluctuations, high incident solar radiation and a high number of sunshine days may lead to good yields at Nakambala, provided that sufficient water is available for irrigation in the dry periods.

According to global climate data, 2005 was the warmest year since 1890, and 2002, 2003 and 2004 featured in the top five warmest years globally. On the estate 2005 was the warmest year, followed by 2002. The estate yields showed good alignment with the DSSAT-Canegro model which predicts increasing yields with increasing temperatures.

The 2005 season findings can be used as an early crop yield indicator on Nakambala estate. Hot and dry conditions in the period November to March could indicate a good cane yield in the season starting in April, provided water is available for irrigation.

The findings and comments in the paper are specific to Nakambala estate.

Keywords: Nakambala yield, drought conditions, warmest year

Introduction

The historic data showed that the 2005 cane crop was the highest recorded on Nakambala estate, both in tons cane per hectare per annum (TCHA) and tons sucrose per hectare per annum (TSHA). This investigation interrogated the estate’s climate database to understand the reason(s) for the high yield. It was assumed that sugarcane husbandry practices on the estate were consistent over the period of the investigation and sufficient irrigation water was available to meet the crop water demand.

The objectives of this paper are twofold. Firstly, to understand the reason(s) for the high yield in 2005 and make recommendations to management on the estate. Secondly, to add the data and findings to the pool of existing knowledge of sugarcane agriculture and make it available to sugar technologists via SASTA proceedings (www.sasta.co.za).

Brief description of Nakambala estate

The sugarcane growing and milling operations are situated on the south bank of the Kafue River. The estate forms part of the Kafue Flood Plain, with a topography that ranges from flat to very flat with slopes of under 2%. Good quality irrigation water is available throughout the cane growing period. Some important agricultural parameters are summarised in Table 1.

Table 1. Brief summary of Nakambala estate as in 2005.

Location	15°50'S and 27°45'E
Altitude (metres above sea level)	970-1000
Area under cane (hectares)	11 052
Soil types (% of area)	Light 29% Medium 52% Heavy 19%
Irrigation types (% of area)	Furrow 96% Centre pivot 4%
Cane varieties (% of area)	N25 (38%) N19 (37%) N23 (11%) N14 (5%) Other (9%)

Cane and sucrose yields

The Nakambala cane and sucrose yields are shown in Table 2, for short periods before and after 2005. The LTM cane and sucrose yields are not shown in this table due to changes in cane varieties and management practices. Periods closer to 2005 are used for comparison purposes.

Table 2. Nakambala estate cane and sucrose yields.

Period	TCHA*	Sucrose % cane	TSHA**
Ave (2000-2004)	109.8	15.1	16.6
2005 season	123.0	14.8	18.2
Ave (2006-2007)	111.6	15.0	16.7

*TCHA = tons cane/hectare/annum
**TSHA = tons sucrose/hectare/annum

Rainfall pattern on the estate

The harvesting season on the estate runs from April to mid-November and any rainfall, for example, recorded after mid-November does not affect the current crop, but the next crop. Therefore annualised climate data can be misleading. The climate data have been realigned to the crop cycle from November to October. For example, the 2005 crop has been aligned to the climate data starting from November 2004 to October 2005. The rainfall pattern on the estate is unique in that 95% of the LTM rainfall is recorded in five consecutive months. The remainder of the season is dry with little or no rainfall. The month by month LTM rainfall and LTM rain days are shown in Table 3 and graphically in Figure 1.The rainfall is generally recorded in the afternoon between 14h00 and 18h00.

Table 3. The 2005 rainfall related data compared with long term mean (LTM) values.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Rainfall													
Rainfall (mm)	38	144	148	24	22	0	0	0	0	0	0	0	376
LTM (mm)	82	162	196	114	106	17	3	0	0	0	1	8	689
Rainfall % LTM	46	89	76	21	21	0	0	0	0	0	0	0	55
Rain days													
Rain days	9	16	13	4	3	0	0	0	0	0	0	0	45
LTM rain days	9	17	18	13	9	2	1	0	0	0	1	2	72
Rain days % LTM	100	94	72	31	33	0	0	0	0	0	0	0	63
Humidity													
Humidity (%)	55.0	68.0	69.0	66.0	65.0	59.0	54.0	54.0	52.0	50.0	50.0	49.0	57.6
LTM	61.6	71.2	74.5	73.9	72.6	65.8	62.6	57.5	55.4	51.6	51.6	53.6	62.7
Humidity % LTM	89.3	95.5	92.6	89.3	89.5	89.7	86.3	93.9	93.9	96.9	96.9	91.4	92.0

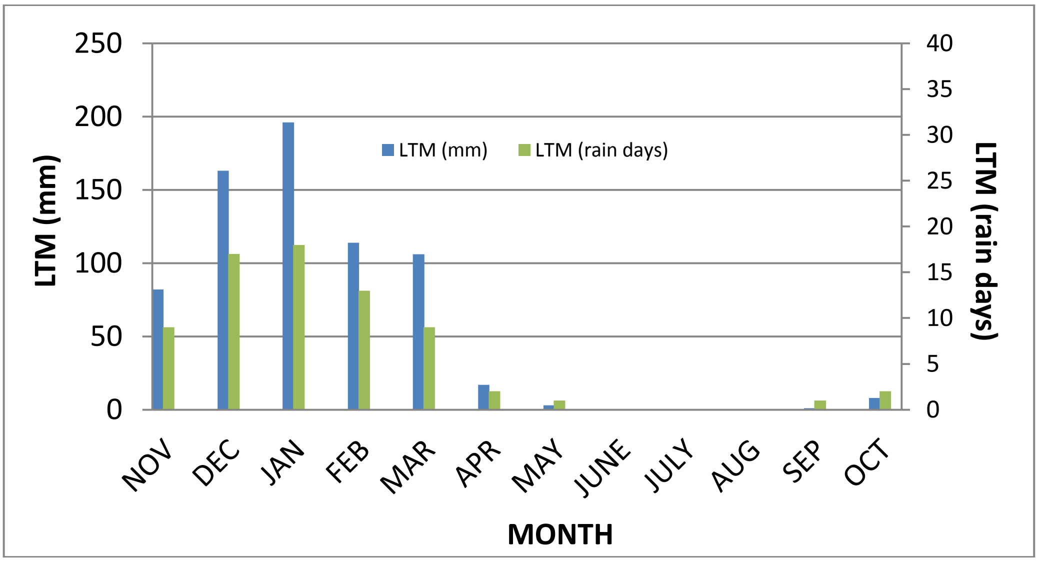

Figure 1. Rainfall pattern on Nakambala estate.

The rainfall data shows that the 2005 season was very dry, with only 55% of the long term mean (LTM) rainfall. The total number of rain days were 62% of the LTM. The relative humidity is measured daily at 08h00 and 14h00 on the estate, and the average was 92% of LTM. Estate employees referred to 2005 as a drought year with massive failure of village crops, and the area had to request emergency food aid. Two articles on the 2005 drought in Zambia can be accessed via the internet (www.unicef.org/zambia and www.afdb.org).

Sunshine hours and radiation

The monthly daily average sunshine hours and the monthly radiation (MJ/m²/month) are shown in Table 4. The sunshine hours and radiation for nine out of the 12 months were above LTM.

Table 4. The 2005 monthly average daily sunshine hours and monthly radiation compared with long term mean (LTM) values.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Ave
Sunshine hours													
Ave daily sunshine hours	8.9	6.3	6.9	9.1	8.8	10.5	10.6	10.4	10.2	10.2	9.9	11.0	9.40
LTM daily sunshine hours	7.9	6.4	6.0	7.0	7.6	9.9	10.1	9.8	9.9	10.3	10.1	10.0	8.75
% LTM	113	98	115	130	116	106	105	106	103	99	98	110	107.4
Radiation													
													Total
Radiation (MJ/m²/month)	782	679	712	736	758	735	680	601	637	708	748	892	8668
LTM	733	682	664	642	694	706	660	582	627	714	760	847	8311
% LTM	107	100	107	115	109	104	103	103	102	99	98	105	104.3

Ambient temperature

The monthly average maximum, average minimum and average temperature range (Δt) are shown in Table 5 for 2005. The temperature range is sometimes referred to as the diurnal temperature. Although the average maximum temperature was above LTM the average minimum temperature was close to the LTM, resulting in a wide temperature range.

Table 5. The 2005 monthly average maximum, minimum and temperature range compared with long term mean (LTM) values.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Ave
Maximum temperatures													
Max °C	30.9	28.9	29.5	31.0	31.7	31.0	29.6	27.5	25.6	30.8	32.2	35.1	30.3
LTM °C	32.3	29.6	29.0	29.3	29.2	28.8	27.6	25.8	25.4	28.6	32.2	33.7	29.3
% LTM	96	98	102	106	109	108	107	107	101	108	100	104	104
Minimum temperatures													
Min °C	18.3	18.9	18.5	18.3	18.2	15.9	13.5	11.8	10.4	14.1	16.1	18.4	16.0
LTM °C	19.1	18.9	18.8	18.5	17.8	15.2	12.6	11.0	10.5	13.1	16.4	18.7	15.9
% LTM	96	100	98	99	102	105	107	107	99	108	98	98	101
Temperature range													
Δt °C	12.6	10.0	11.0	12.8	13.5	15.1	16.1	15.7	15.2	16.7	16.1	16.7	14.3
LTM Δt °C	13.3	10.7	10.2	10.8	11.4	13.5	14.9	14.8	14.9	15.4	15.8	15.0	13.4
% LTM	95	94	108	119	118	112	108	106	102	108	102	111	107

Discussion of findings

The rainfall pattern in Table 3 shows that 95% of the LTM rainfall is received in five consecutive months (November to March) of the year. The months of May to October have little to no rain. Since rain and the associated cloud cover influence a number of other important cane growth parameters, the November to March rainfall and rain days have an important influence on the cane crop. The rain on the estate generally falls in the afternoon between 14h00 and 18h00 and this reduces incident radiation availability to the crop. The influence of the low rainfall and low rain days on the other cane growth parameters is shown in Tables 3 to 5, and is summarised in Table 6.

Table 6. Summary of the 2005 cane growth parameters.

Growth parameter	2005	% LTM
Rainfall (mm)	376	55
Rain days	45	63
Relative humidity	57.6	92
Daily average sunshine hours	9.40	107
Average maximum temperature (°C)	30.3	104
Average minimum temperature (°C)	16.0	101
Temperature range (Δt °C)	14.3	107
Total radiation (MJ/m²/annum)	8668	104

The January, February and March data is shown in Table 7 and is compared with the LTM for the same period. The effect of the below LTM rainfall and rain days on the other climate data in this period is very pronounced. For example, the sunshine hours for the period January to March was 120.3% above LTM and the radiation was 110.3% LTM. Although the maximum temperature was above LTM the minimum temperature was slightly below LTM, resulting in a wide temperature range of 115% of LTM.

Table 7. Summary of the January, February and March 2005 cane growth parameters.

Growth parameter	Jan	Feb	Mar	Ave (Jan-Mar)
Rainfall % LTM	76	21	21	39.3
Rain days % LTM	72	31	33	45.3
Relative humidity % LTM	93	89	90	90.7
Sunshine % LTM	115	130	116	120.3
Max temp % LTM	102	106	109	105.7
Min temp % LTM	98	99	102	99.7
Temp range % LTM	108	119	118	115.0
Radiation % LTM	107	115	109	110.3

Mid to long term climate forecasts are becoming more reliable (Lumsden *et al*., 1998) and serve as the best indication of future climatic conditions. In the absence of reliable radiation and temperature forecasts, rainfall can be used as a surrogate. High rainfall is usually associated with low radiation and temperature (McGlinchey, 1999). The data presented in Table 3 shows that 95% of the estate's rainfall is recorded in the period November to March. The November to March rainfall or forecast can be used as an early indicator of the crop on the estate. The January to March rainfall pattern, being closer to the start of the season in April, can give a better indication of the crop yield on the estate than the November to March rainfall. The LTM radiation in January to March ranges between 664 and 694 MJ/m²/month.

Dry conditions in these three months can increase both radiation and maximum temperature and provide a strong boost to the crop, as was the case in 2005.

The 2005 conditions recorded on the estate were not unique to the estate. Global weather patterns are monitored by a number of institutions and good references are NASA's Goddard Institute for Space Studies (GISS) and the National Climate Data Centre, which ranked 2005 as the warmest year since 1890 (www.nasa.gov/vision/earth/environment/2005). The 2005 average maximum temperature of 30.3°C on the estate was the highest since record keeping began in 1964. The years 2002, 2003, 2004 and 2005 featured in the top five warmest years globally with 2002 recording the second highest temperature on the estate. The cane yields were also high during the warm years of 2002-2004. The effect of rising temperatures on estate cane yield is shown in Table 9.

Table 9. The effect of rising temperatures on Nakambala estate cane yields.

Period	Ave max temp (°C)	Radiation (MJ/m^2/annum)	TCHA*	Sucrose % cane	TSHA**
2000-2001	28.6	8279	101.8	15.2	15.5
2002-2004	29.1	8415	115.2	15.0	17.3
2005	30.3	8668	123.0	14.8	18.2
2006-2007	29.2	8234	111.6	15.0	16.7

*TCHA = tons cane/hectare/annum
**TSHA = tons sucrose/hectare annum

The data in Table 9 is in line with the predictions of the DSSAT-Canegro sugarcane model which predicts higher cane yields with rising temperatures (Jones *et al*., 2013).The model was used to predict the effect of global warming on cane yields. The model also predicts lower sucrose yields because of additional consumption of photo-assimilate by increasing rates of maintenance respiration. This effect is seen in the 2005 yield where biomass production went up but the sucrose % cane came down.

The data in Tables 3 to 5 show above ground climatic conditions. However, a very important part of the cane plant, the roots, is under ground level. A healthy root system improves the overall health of the cane plant. It is well known and accepted amongst soil scientists that soil aeration is very important. Gosnell (1971) studied the effect of the ground water table on cane yields and found that a shallow water table had serious effects on cane yield. Changing the water table from 100 to 25 cm resulted in a 63% decrease in cane yield. For optimum cane growth, the water table should be kept below 1 m. Juang and Uehara (1971) carried out trials with water table depths maintained at 80, 50 and 30 cm and found that sugarcane performed best with the water table held at 80 cm. Bhattarai *et al*. (1999) studied the effect of soil oxygen on crop yields and stated that in climates with high soil and air temperatures during the growing season, crops are likely to be prone to stress from poor aeration, and even more so if grown on heavy soils that are temporarily saturated (with water). About 71% of the cane area at Nakambala have medium to heavy soils.

There is evidence on the estate that waterlogging affects cane yields, with heavy soils producing low yields during high rainfall seasons and *vice versa*. Figures 2 and 3 show two sections of cane, of the same variety and age, grown on the same field about 20 m apart. The waterlogging was due to a leak in the irrigation canal. The cane grown on the wet section was very poor compared to the one grown on the dry section of the same field.

Figure 2. Cane grown on a wet section of a field.

Figure 3. Cane grown on dry section of the same field.

The period 2002 to 2004 received 87% of the LTM rainfall and 2005 received only 55% of the LTM rainfall. Although the ground water table was not measured in 2005 it can be speculated that the below LTA rainfall had an influence on ground water level and root aeration and played a part, be it small, on the 2005 yield. The estate records show that the Kafue river level dropped by about 1 m and the suctions on the irrigation pumps had to be extended by 1 m.

In 2005 the Nakambala crop produced a very high yield, with only 55% of the LTM rainfall. Rainfall cannot be controlled, but drainage infrastructure and management practices can be tailored to simulate low rainfall by quickly draining away excess water. The drainage of excess rain water also plays an important role in flushing out salts such as sodium, which can accumulate, making the soil sodic and leading to lower yields. The rainy period should be a very busy time for irrigation employees in a 'reverse' role – to drain and remove rain water, compared to conserving water during irrigation. Nakambala management should also implement practices that promote root aeration. Measuring the water level in strategically placed sample pits of 1.5 m deep can give a good indication of ground water levels on the estate. Understanding the soil types and the water holding capacities of the different soils is very important. This information can be used to tailor irrigation practices on the estate.

Conclusion

The data indicates that the high cane and sucrose yield in 2005 was due to warm and dry conditions on the estate brought about by 55% of LTM rainfall. The decreased level of cloud cover increased the total sunshine hours (107% of LTM), increased maximum temperature to 30.3°C (104% of LTM) and produced a wide temperature range of 14.3°C (107% LTM). Since 95% of the LTM rainfall is received between November and March, the rainfall and the rain days in this period can be used as an early yield indicator on the estate. The rainfall in the period January to March, being closer to start of the new season in April, can be a better yield indicator on the estate.

The year 2005 was ranked the warmest year globally since 1890. This was also experienced on the estate, with 2005 being the warmest year since record keeping began in 1964. The years 2002, 2003 and 2004 were ranked in the top five warmest years globally and this period showed a steep increase in cane yields. The estate yields are in line with the DSSAT-Canegro sugarcane model predictions.

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