HOMOGENEOUS CLIMATE ZONES FOR THE SOUTH AFRICAN SUGAR INDUSTRY: PRELIMINARY BOUNDARIES

C N BEZUIDENHOUT and C GERS

South African Sugar Association Experiment Station, P/Bag X02, Mount Edgecombe, 4300, KwaZulu-Natal, South Africa
E-mail: bsf@sugar.org.za

Abstract

Sugarcane in South Africa is grown under a wide range of climatic conditions and requires a range of varieties and localised agronomic practices. Point-based climatic data and models have been used to derive both tactical and strategic recommendations. Such results need to be extrapolated to larger areas, which necessitates the need to identify reasonably homogeneous climate zones. Previously described boundaries of rainfall zones were carefully revised after taking into account (1) the sugar producing areas, (2) altitude and (3) mean annual precipitation estimates. The results were presented to area extension officers who proposed further subdivision of some zones. Boundaries were tested by comparing the climate variability of the new zones with that of previously derived zones and by quantifying the difference between neighbouring zones. The proposed zones can be used to identify strategic points for data collection. They can also support the extrapolation of recommendations and model output, which in term will support strategic and tactical decision-making.

Keywords: Climate, Rainfall, Radiation, Temperature, Map

Introduction

Sugarcane in South Africa is grown under a wide range of climatic conditions and requires a range of varieties and localised agronomic practices. Point-based climatic data and models can be used to support both tactical and strategic decision-making. For example, herbicide scheduling can be based on the time taken to canopy closure derived from local weather conditions. Similarly, point based climatic data have been used by Inman-Bamber (1995) and Bezuidenhout and Singels (2001) to benchmark and estimate cane yields respectively.

Recommendations and model results, however, need to be extrapolated to larger areas where no climate data are available. Therefore, it becomes important to identify geographical zones in which climate variability can be assumed to be negligible.

Three previous studies derived geographical zones that relate to this study. Dent *et al.* (1989) compiled 712 homogeneous rainfall zones for South Africa. In this study, however, no consideration was given to variability in temperature and radiation. The zones have since become outdated by the acquisition of newer data and in the process some of the boundaries have been contradicted (*pers comm.*, R. Schulze, University of Natal). Camp (1999) derived homogeneous bio-resource units based on climate, soil and topography for KwaZulu-Natal. Limitations of the study were that (1) sugar-producing areas in Mpumalanga were excluded and (2) bio-resource units were strongly based on underlying soil classifications rather than climate. Midgeley *et al.* (1994) compiled geographical units based on watersheds of quaternary catchments for South Africa. The quaternary catchments were derived from topographical characteristics rather than climate. Although an association between topography and climate can be expected, there is a need to assess the climate homogeneity within and across these proposed units.

In the light of the above-mentioned limitations, the aim of this study was to assess the suitability of existing zones and, where necessary, to redefine homogeneous climate zones applicable to the S.A. sugar industry.

Methods

Provisional boundaries were based on the rainfall zones described by Dent *et al.* (1989). These zones included large areas where sugarcane is not grown, such as game reserves, steep river valleys and urban areas. Such areas were excluded to enable more constructive suggestions from local extension officers and to generate statistics that are more representative. Dent *et al.* (1989) focussed primarily on rainfall variability and excluded variability in temperature. Therefore, temperature variability was included by subdividing zones where altitude differed by more than 600m. In conjunction, a more recent 1km x 1km mean annual precipitation (MAP in $mm.an^{-1}$) data set (Schulze, 1997) was used to ensure the overall MAP range in zones did not exceed 200mm. The results were evaluated by SASA extension officers and based on their experience of local climate, some zones were further subdivided. However, in the Midlands north region the proposed zones were (1) larger than in other areas, (2) the range of MAP within zones was higher than 300mm, (3) the local extension officer disagreed with the proposed boundaries and (4) some patterns in MAP stretched across zones. To rectify this, new zones for this region were derived by combining bio-resource units derived by Camp (1999).

Mean annual solar radiation (SR in $MJ.m^{-2}.an^{-1}$), mean annual heat units with a 10°C base temperature (HU in $°C.d.an^{-1}$) and MAP were selected to assess the homogeneity of zones. These data were taken from Schulze (1997) and had a 1' x 1' resolution.

A coefficient of variation for each zone (CV) was calculated by averaging the coefficient of variation for MAP, HU and SR. These results were compared with similar results for the quaternary catchments. The mean CV value over all zones in the industry was calculated and zones with CV values that were more than double that were highlighted for further investigation.

A second test was conducted to quantify the uniqueness of a zone amongst it's neighbours. This was based on Euclidean distances, similar to the work of Stahl and Demuth (1999) and Bartlein (1997). In this test the average discrimination of Zone X ($\overline{D_X}$) was calculated (Eq. 1). The value of $\overline{D_X}$ would typically vary between 0% and 100%, reflecting very high uniqueness when approaching 100%. The mean $\overline{D_X}$ value over all zones was calculated and zones with $\overline{D_X}$ values less than half that were highlighted for further investigation.

$$\overline{D_X} = \frac{1}{N}\sum_{Y=1}^{N} D_{X,Y} \qquad (1)$$

where Y (1..N) are neighbouring zones to Zone X and $D_{X,Y}$ is a discrimination index between Zone X and Zone Y (Eq 2.).

$$D_{X,Y} = \left[1 - \frac{\bar{\partial}_X}{\bar{\partial}_{X,Y}}\right] \times 100 \qquad (2)$$

where $\bar{\partial}_X$ is the average Euclidean distance (Eq. 3) between normalised data points in Zone X and $\bar{\partial}_{X,Y}$ is the average Euclidean distance between normalised data points in Zones X and Y combined.

$$\partial_{i,j} = \sqrt{\left(MAP'_i - MAP'_j\right)^2 + \left(HU'_i - HU'_j\right)^2 + \left(SR'_i - SR'_j\right)^2} \quad (3)$$

where *i* and *j* refer to different data points and MAP', HU' and SR' are normalised values according to their range in Zones X and Y combined.

Results

Figure 1 and Table 1 reflect the derived climate zones for the sugar industry. The mean CV for the 49 proposed climate zones was 4.96% and the average area per zone was 453km^2. The mean CV for the 118 quaternary catchments was 6.08% and the average area per catchment was 365km^2. The Umfolozi flood plains and High flats zones had the lowest CV values (CV<2.2%).

The mean discrimination index over all zones was 37.2% (see Table 1). Zululand river valley and Illovo were the most distinctively different from their neighbours ($\overline{D_X}$ >65%) after excluding isolated cane areas (such as Muden). Results from six zones were poor and were highlighted for further investigation (Table 1).

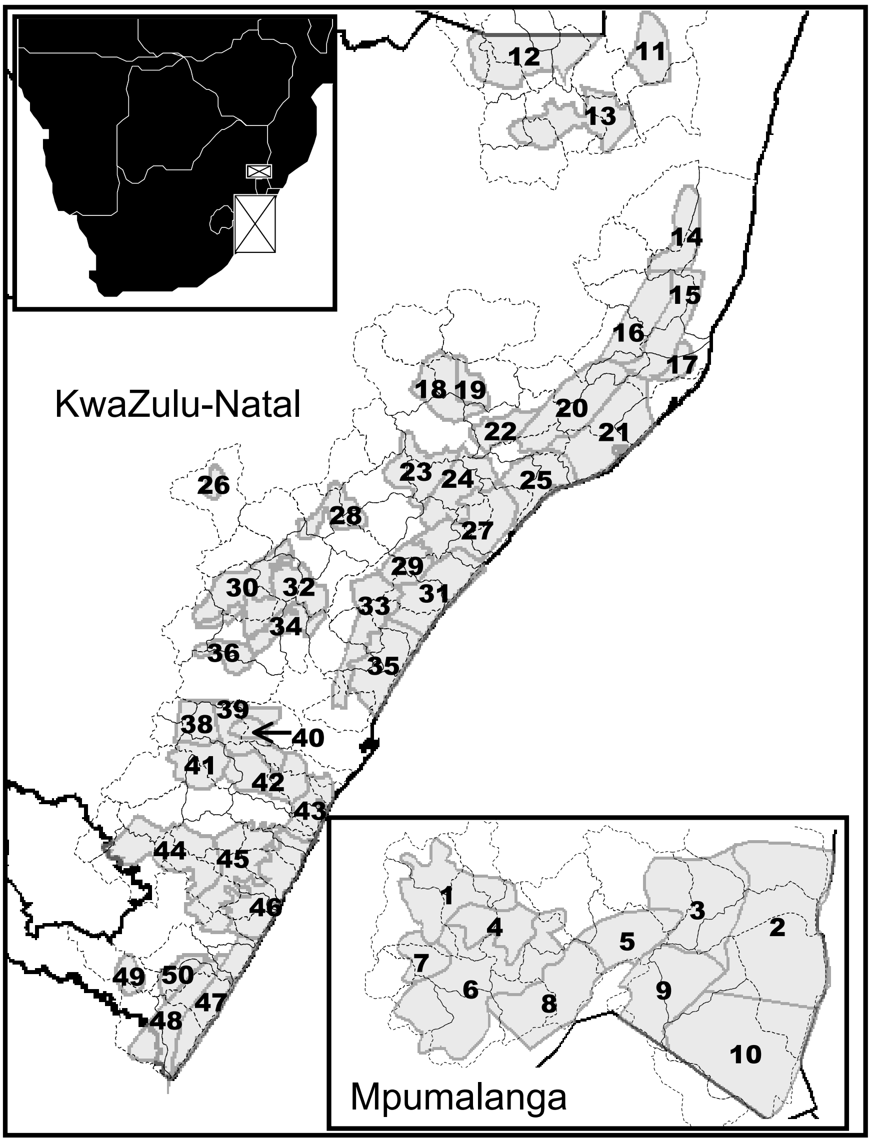

Figure 1. Proposed homogeneous climate zones for the sugar industry (shaded and numbered). Quaternary catchments are indicated by dotted lines.

Table 1. Summary of the proposed climate zones. Each zone's area, mean annual solar radiation (SR), mean annual heat units (HU), mean annual precipitation (MAP), average coefficient of variation (CV) and average discrimination index ($\overline{D_X}$) are reflected. Shaded zones have been highlighted for further research due to poor test results.

Zone No.	Name	Area (km^2)	SR ($MJ.m^{-2}.an^{-1}$)	HU ($°C.d.an^{-1}$)	MAP ($mm.an^{-1}$)	Mean CV (%)	$\overline{D_X}$ (%)
1	Nelspruit	420	8432	3425	834	4.6	26.1
2	Komati	1115	8593	4455	583	4.0	58.6
3	Hectorspruit	595	8576	4288	670	7.5	29.7
4	Gorge	221	8431	3540	777	6.5	9.5
5	Malalane / Kaapmuiden	277	8523	4078	776	8.2	20.2
6	Barberton	854	8432	3368	854	8.4	-3.4
7	Kaapse hoop	129	8438	3202	862	5.0	19.1
8	Kaapmuiden	450	8355	3537	908	12.7	-4.1
9	Kaalrug / Richterhoek	450	8516	4146	849	8.9	5.0
10	Komati projects	921	8472	4214	672	5.6	43.1
11	Makatini flats	335	8210	4420	577	4.7	69.7
12	Pongola	767	8496	4153	627	2.8	13.0
13	Mkuzi	611	8308	4149	625	7.2	31.1
14	Hluhluwe	364	7812	4348	741	4.9	44.9
15	Mtubatuba	541	7653	4311	950	2.8	46.6
16	Mzondeni strip	517	7854	4266	842	2.9	53.9
17	Umfolozi flood plains	121	7504	4321	1150	1.8	50.1
18	Zululand mistbelt	419	7773	2910	937	2.3	27.1
19	Zululand hinterland	154	7874	3253	872	6.2	48.6
20	Heatonville	746	7631	4118	955	4.0	39.3
21	Empangeni	827	7363	4181	1191	3.4	36.7
22	Zululand river valley	223	7697	3981	790	4.2	65.8
23	Entumeni	427	7794	3325	935	2.9	28.8
24	Eshowe	474	7529	3541	1082	7.6	53.6
25	Emoyeni	485	7284	3982	1241	3.9	41.8
26	Muden	62	8636	3106	650	4.2	74.9
27	Amatikulu	663	7346	3921	1020	5.8	32.3
28	Kranskop mistbelt	278	7663	2507	913	3.5	59.9
29	Doornkop	257	7415	3480	1049	5.9	34.9
30	New Hanover	458	8095	2760	977	5.0	29.9
31	Upper North coast	616	7222	3842	1012	7.8	42.8
32	Wartburg / Fawnleas	561	7890	2772	867	2.4	32.3
33	Upper Tongaat	525	7373	3426	956	4.9	34.8
34	Windy Hill mistbelt	244	7720	2668	981	5.3	49.6
35	Lower North coast	586	7190	3763	986	4.6	38.1
36	Hilton / Umgeni valley	174	8001	2970	892	2.2	25.7
38	Baynesfield	271	7890	2629	912	7.0	29.3
39	Eston / Camperdown	381	7683	2901	810	5.8	32.5
40	Tala valley	94	7732	3039	720	4.0	36.0
41	Richmond	343	7848	2915	839	3.7	14.9
42	Mid Illovo	452	7423	3134	874	6.2	36.9
43	Illovo	317	7095	3675	985	4.8	65.3
44	High-flats	730	7685	2587	816	2.1	45.8
45	Dumisa	708	7436	3311	883	5.6	43.7
46	Sezela	668	7236	3674	1000	4.6	28.9
47	Umzimkulu coastal	527	6875	3629	1088	3.9	54.0
48	Paddock / North bank	557	7048	3287	952	2.7	20.1
49	Hlaku / Nqabeni	125	7529	2958	775	6.1	72.5
50	Oribi / North Paddock	162	7241	3126	870	2.2	34.1
	Mean	**453**	**7813**	**3543**	**880**	**4.96**	**37.2**

Conclusion and discussion

In general, the proposed homogeneous zones were larger, more specific to the sugar industry and more uniform than the quaternary catchments. Test results highlighted six problematic zones, primarily in Mpumalanga. Further research is necessary to rectify these problems.

Once satisfactory the zones can be used to identify strategic points for data collection and can support the extrapolation of scientific recommendations and model output. This may benefit a wide range of climate-specific issues, for example crop forecasting (Bezuidenhout and Singels, 2001), determining pest and disease sensitive areas, and extrapolating variety and other agronomic recommendations.

Acknowledgements

Invaluable assistance and information regarding local climate and cane production areas were supplied by F. Botha, B. Swart, S. v.d. Walt, T. Culverwell, A. Jones, R. Fortmann, P. Brenchley, G. Lagerwall, R. Stranack, E. Hulbert, G. Maher, D. Hellmann, D. McElligott, G. Buchanan and M. Eweg (SASEX Extension services), as well as A. Simpson (Illovo), W. Gillham (Alexandra group), J de Lange (Illovo) and G. Groom (S.A. Cane Growers Association). J. Lambrecht (Transvaal Suiker Bpk.) assisted with GIS mapping for Mpumalanga. Prof. R. Schulze (University of Natal) and Dr. A. Singels, E. Schmidt and R. Donaldson (SASEX) provided valuable comments and guidance.

REFERENCES

Bartlein, PJ (1997). *Past and Future Rapid Environmental Changes: The Spatial and Evolutionary Responses of Terrestrial Biota.* In: Huntley, B, Cramer, W, Morgan, AV, Prentice, HC and Allen, JRM (Eds.), NATO ASI Series, Vol. 147, pp 11-29.

Bezuidenhout, CN and Singels, A (2001). The use of simulation crop modelling to forecast sugarcane yield. Proceedings of the SASTA workshop on burn/harvest to crush delays and crop estimating. 8 November 2002, Mt. Edgecombe, South Africa, pp 20-29.

Camp, K (1999). Bioresource classification of KwaZulu Natal. M.Sc. thesis, University of Natal, 140 pp.

Dent, MC, Lynch, SD and Schulze, RE (1989). Mapping mean annual and other rainfall statistics over Southern Africa. Water Research Commission, Pretoria, Report 109/1/89, 188 pp.

Inman-Bamber, NG (1995). Climate and water as constraints to production in the South African sugar industry. *Proc S Afr Sug Technol Ass* 69: 55-59.

Midgley, DC, Pitman, WV and Middleton, BJ (1994). The Surface Water Resources of South Africa 1990 (1st edn.). Volumes 1 to 6. Report Numbers 298/1.1/94 to 298/6.1/94 (text) and 298/1.2/94 to 298/6.2/94 (maps) and CD-ROM with selected data sets. Water Research Commission, Pretoria.

Schulze, RE (1997). South African atlas of agrohydrology and climatology. Water Research Commission, Pretoria, Report TT82/96.

Stahl, K and Demuth, S (1999). Methods for regional classification of streamflow drought series: Cluster Analyses. Technical report No.1 on Assessment of regional impact of droughts in Europe. University of Freiburg, Germany.