CARTOGRAPHIC PRESENTATION OF SEASONAL WATER-TABLE FLUCTUATIONS ON SENA SUGAR ESTATES, LUABO, ZAMBESIA

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Abstract

A method of cartographic presentation of ground water level fluctuations is discussed.

In 1960, a system of ground water-table class mapping was introduced in the Netherlands by the Netherlands Soil Survey Institute (STIBOKA). Since the soil physiographic conditions at the Luabo Estate, involving large areas of extremely flat land, resemble conditions as they are found in the Netherlands, the STIBOKA system was applied to Luabo conditions. It was found that the average curves derived from 3 years of observations of the water level fluctuations could be considered indicative of the ground water level fluctuations in a year of average climatological conditions. With the help of mean fluctuation curves derived from 3 years' observations, mean highest and mean lowest ground water levels (MHG and MLG values) were established. During soil mapping, these MHG and MLG values were estimated whenever a boring was carried out or a profile pit examined. Soils with equal MHG and MLG values were combined into mapping units. Realizing the limitations of only 3 years' data, five water-table classes were distinguished. The application and importance of water-table class mapping in land capability studies is emphasized.

Introduction

At the Luabo Estate a good knowledge of the water relations of the soils is essential for the appraisal of irrigation and drainage problems and for a better evaluation of the hazards of soil salinity and alkalinity.

Although seasonal water-table fluctuations present only one aspect of the water relations of the soils, the importance of this aspect is accentuated by the fact that large areas of flat land are involved. The need to investigate, record and present cartographically the seasonal fluctuations of the ground water-table may be illustrated by the following considerations:

(*a*) *Effect of the depth of the ground water-table on sucrose and cane yields*

Continuous high water-tables maintained in drums showed a pronounced adverse effect on the yield of sucrose per unit area, particularly at 25 and 50 cm water-table levels (Gosnell, 1971). This author also found that there was a greater sucrose yield depression with progressive ratooning at the shallow water-table levels than at the deeper ones and that little difference was apparent between the 75, 100 and 125 cm water-tables.

(*b*) *Depth of the ground water-table in relation to the hazards of salinity and alkalinity*

Ground waters at the Luabo Estate are often of a poor quality. EC values in excess of 4 000 micromhos are no exception and values as high as 11 000 micromhos have been recorded. Sodium is usually the predominant cation and chloride the predominant anion present (Lapperre, 1969).

Marshall (1959) points out that the control of salts is mainly a matter of controlling the water movement and thus to a considerable extent controlling the movement of the water-table. Gosnell (1971) found an alarming sodium build-up at 45-60 cm with a water-table kept continuously at 75 cm. He found a marked build-up in total salts above the 25 and 50 cm water-tables and an appreciable build-up with the 75 cm water-table level.

The work of Gardner and Fireman (1958) suggests that the movement of salts near the surface is likely to be serious if the water-table is less than approximately 100 cm below the surface. Gosnell (1971) comes to a similar conclusion.

In British Guiana, Wilkins and Athesian (1965) found that under non-saline conditions the depth of the water-table should be set at 146 cm and under saline conditions at 320 cm.

Talsma (1963) points out that any critical depth of the water-table varies with the soil texture.

(*c*) *Depth of the ground water-table in relation to irrigation control and drainage design*

The management of the overhead irrigation scheme is based on a daily soil moisture 'profit-and-loss account'. Irrigation and effective rainfall are plotted against potential evapotranspiration obtained from Class A Pan readings and certain canopy factors. The system is based on an effective rooting zone of 60 cm and estimated TAM values for each field.

The presence of a high and fluctuating water-table constitutes a most difficult problem in such an irrigation control system, since the extent to which the water-table contributes to the cane's water requirements cannot be easily measured.

From the work mentioned under (*b*) it is apparent that if a water-table is present, it should be kept at least at 100 cm in the case of non-saline ground waters and probably much deeper in the case of saline ground waters. A cartographic presentation of ground water-table fluctuations would therefore greatly facilitate the design of a suitable drainage system.

General aspects of the area mapped

The Luabo Estate of Sena Sugar Estates Limited, is situated on the North bank of the Zambesi river, at approximately 36° E and 18° S, some 60 kilometers from the Indian Ocean. The total area under sugar cane cultivation amounts to about 10 000 hectares, of which 6 800 hectares are irrigated.

The landscape reflects the patterns of an alluvial plain. In general the area is extremely flat, but due to the occurrence of river levees, sand bars, basin areas and abandoned channels, some local variation in level exists within the narrow range of about 4 meters.

The course of the inland rivers is south-eastward, according to the overall slope of the land which amounts to about 1 : 5 000.

Under natural conditions flooding of areas like the Luabo Estate is common in periods of high water and abundant rainfall.

As this would be detrimental to the development of the crop, the area under cultivation has been surrounded by a dike system.

The soils were classified according to the Comprehensive System of Soil Classification of the United States Department of Agriculture, 7th Approximation (1960) and its Supplement (1967).

They belong to three orders: the vertisols, the inceptisols and the mollisols (Lapperre, 1971).

The vertisols (usterts) are characteristic of the extensive basin areas and some of the abandoned and filled channels and consist of deep, black clays. The inceptisols (umbrepts) are characteristic of the highest parts of the levees and bars and consist of medium and light textured loams and fine sands. The mollisols (dominantly arguistolls) occur on the natural levees, splays, point bars and river bars and consist of deep loams.

Materials and methods

Early in 1966, Sena Sugar Estates consulted the International Institute for Land Reclamation and Improvement (IILRI), Wageningen, The Netherlands. In accordance with their suggestions observations of the water-table fluctuations were started.

Installation of observation tubes

During 1966, observation tubes were installed in a grid system; one tube for every 4 fields (approximately 48 hectares) in the irrigation development area. Tubes were made from black polythene tubing. 3,5 cm in diameter and 275 cm long — the lower 76 cm being perforated. These were inserted in 260 cm deep auger holes. All tubes were closed with perforated wooden stoppers and in each case the length of tube above the ground surface was measured. Sites near rivers, roads, compounds, irrigation canals and main drains were avoided.

Recording

Records were collected weekly at a pre-determined date and measurements were expressed in centimeters below the soil surface.

For each month a point map was prepared, presenting five arbitrary classes of mean ground water levels. Table I presents these classes.

TABLE I

Ground water level classes

Classes	Depth below ground level in centimeters		
I			50 cm
II	50	—	100 cm
III	100	—	150 cm
IV	150	—	200 cm
V			200 cm

By simple interpolation this point map was then transposed into a map showing area units. This procedure was used until 1970, but has since been revised to fit the procedures currently followed. The main aspects demanding revision were the following:

(*a*) The polythene tubing as suggested by the IILR proved to be unsatisfactory as the yearly burning of cane prior to harvest resulted in the destruction of a great number of observation tubes. During 1970, all polythene tubes were therefore replaced by galvanized iron tubes.

(*b*) The placement in a grid system was no longer considered satisfactory. Since tubes were placed at regular intervals, many of them were not representative of the surrounding soils and consequently irrelevant information was being collected at considerable expense. Tubes are now being installed in representative locations by making extensive use of the existing soil maps. It is hoped that more direct and reliable information will be obtained in this way. A limited number of carefully selected old tubes remain operative, in order to retain and augment information collected during 1967, 1968, 1969 and 1970.

(*c*) As was mentioned previously, point maps with five purely arbitrary ground water-table classes were prepared monthly and interpolated to obtain area units. This procedure introduced serious errors as it disregarded the relationship between ground water level fluctuations and such features as topography, relief and profile characteristics.

When the author undertook to carry out a detailed soil survey of a number of sample areas during 1970, new ways of transposing point information to map unit information with regard to the ground water-table fluctuations were considered.

In order to achieve this objective, ground water-table classes in the form of the STIBOKA system were introduced.

STIBOKA system of ground water-table fluctuation recording

In 1960, a rather sophisticated system of ground water-table class mapping was introduced in the Netherlands by the Netherlands Soil Survey Institute (STIBOKA).

A brief review of this system is given.

The ground water level in any particular location fluctuates during the course of the year. Generally speaking, the ground water will be higher during the rainy season and lower during the dry season. If a rise and fall of the ground water is plotted against time, the result will be a yearly ground water level fluctuation curve. For the same location this curve will have a different shape for different years, owing to the differences in rainfall and evapotranspiration. The STIBOKA system is based on what is called the "mean highest ground water level" (MHG) and the "mean lowest ground water level" (MLG). These values are obtained by drawing an average curve for a certain number of years (under Dutch climatological conditions a minimum of 8 years) and determining the top and bottom of this curve, respectively the MHG and the MLG.

Such an average ground water level curve should be considered indicative of the ground water level fluctuations in a year of average climatological conditions (Heesen and Westerveld, 1966). Table II presents the ground water-table classes (MHG and MLG limits) as at present used in the Netherlands on soil maps of 1 : 50 000 scale.

TABLE II

Ground water-table classes as at present used in the Netherlands on soil maps of 1 : 50 000 scale

Classes	I	II	III	IV	V	VI	VII
Ground water levels in centimeters below the surface							
MHG	—	—	40	40	40	40-80	80
MLG	50	50-80	80-120	80-120	120	120	120

In the field the various ground water classes are estimated with the help of certain profile and terrain characteristics. This implies that the relationship between the MHG and the MLG and those profile and field characteristics is known. This knowledge can be obtained by detailed profile studies on sites where ground water measurements have been carried out for a number of years (Heesen, 1970).

STIBOKA system as applied to the Luabo Estate area

Various factors made it difficult to apply this system of ground water-table classes to the Luabo area. Observations of the ground water-table fluctuations were started in 1967 and consequently the data of 3 years only were available when compiling the ground water-table classes map.

This implies that the MHG and MLG values derived from these observations were probably inaccurate, as at least 8 years of continuous observations would be required.

Furthermore, at the Luabo Estate various factors interfered with the natural pattern of ground water-table fluctuations, the two most prominent being the introduction of overhead irrigation in 1966 and improved drainage conditions since 1967.

Also factors of a more technical nature interfered with the accuracy of data; for example, precipitation was recorded at the Luabo meteorological station and not at the observation tube sites. In individual years this might have led to discrepancies in the correlation of rainfall and ground water-table fluctuations. Despite the fact that the STIBOKA advises not to measure tubes in the event of precipitation or irrigation 3 days prior to the recording date, the water-table was measured on a specific day irrespective of any rain prior to the measurements. In individual years this too might have led to discrepancies.

The question now arises to what extent the average curves of only 3 years are representative of the average conditions of a greater number of years. Assuming a fair correlation between precipitation and fluctuations of the ground water-table, this could be checked by comparing the precipitation records of 1967, 1968 and 1969 with the 19 years average. Furthermore, the question arises whether or not the mean highest and lowest ground water-tables as derived from 3 years' curves, correspond with certain profile characteristics.

As observations of the ground water-table fluctuations were started simultaneously with the introduction of overhead irrigation and drainage improvement, this point cannot be taken for granted.

Precipitation and evapotranspiration as related to the fluctuations of the ground water-table

The relationship between precipitation, evapotranspiration and the fluctuation of the water-table in a large number of observation tubes was studied and a good correlation was found between precipitation, evapotranspiration and ground water-table fluctuations.

To establish the extent to which the average precipitation for 1967, 1968 and 1969 was representative for the 19 years' average, a comparison was made, based on the monthly means. Table III presents this comparison.

TABLE III

Comparison of 3 years precipitation (1967-1969) with the 19 years average

Month	1967-1969	19 years average	+	—
J	177	219		42
F	150	188		38
M	183	170	13	
A	156	83	73	
M	69	53	16	
J	45	53		8
J	53	30	23	
A	34	19	15	
S	17	14	3	
O	86	18	68	
N	45	77		32
D	174	173		1

From the data presented in Table III it is apparent that the 3 years' average for April is considerably higher than the 19 years' average. Not only is the average higher, but also the individual years show an unusually high rainfall in April. The high 3 years' average for October can be attributed to the exceptional amount of 246 mm, recorded in 1969.

Table IV compares the monthly averages for evapotranspiration with the monthly averages for precipitation during 1967, 1968 and 1969.

TABLE IV

Monthly comparison of precipitation and evapotranspiration for the years 1967 to 1969

Year	Month	EvTr (class A)	Precipitation	Deficit	Surplus
1967	J	221	311		90
	F	213	251		38
	M	124	264		140
	A	145	169		24
	M	110	74	36	
	J	100	80	20	
	J	82	81	1	
	A	139	47	92	
	S	165	30	135	
	O	233	4	229	
	N	230	14	216	
	D	167	118	49	
1968	J	184	79	105	
	F	118	133		15
	M	179	121	58	
	A	112	109	3	
	M	78	67	11	
	J	93	9	84	
	J	98	10	88	
	A	135	9	126	
	S	177	5	172	
	O	223	7	216	
	N	169	92	77	
	D	197	144	53	
1969	J	178	141	37	
	F	186	67	119	
	M	158	165		7
	A	141	191		50
	M	126	67	59	
	J	92	45	47	
	J	94	69	25	
	A	100	47	53	
	S	140	1	139	
	O	187	246		59
	N	217	31	186	
	D	188	261		73

From the data presented in Table IV it is apparent that the water deficit increases from April onwards, reaching its maximum during September, October and November. Generally the period from April to July is characterized by a moderate water deficit.

After studying the time curves of the changes in the water-table levels of a large number of observation tubes, the following was observed:

(*a*) On the loamy and sandy textured soils, the fall in ground water level generally coincides with the increasing recorded water deficit from April onwards. A distinct rise in the ground water level is usually recorded again in November and December. Generally the time curves of the loamy and sandy textured soils show a large amplitude, whilst the time curves of clayey textured soils show a much smaller amplitude.

(*b*) On the clayey textured soils, a slight fall in ground water level occurs from April onwards and coincides with the period of moderate water deficit. June, quite surprisingly, often shows a rise in the ground water levels, but by the end of July the level again falls. This fall coincides with the rapidly increasing water deficit from July onwards.

Reviewing the results of the comparisons of precipitation, evapotranspiration and the time curves of the changes in water-table levels, one can say that there is a fair correlation between the three. This correlation is more distinct in the case of loamy and sandy soils than for the clayey textured soils.

It is felt that the analysis of precipitation, evapotranspiration and the time curves of the changes in water-tables justifies the conclusion that the 3 years ground water-table curves give a fair impression of the situation in a year of average climatological conditions.

Water-table classes as related to profile and field characteristics

The relationship between water-table classes (MHG and MLG values) and profile and field characteristics was studied from a large number of soil profiles located near observation tubes.

Figures 1 to 5 present the time curves of the changes in water-table levels and the MHG and MLG values for a number of representative profiles obtained during 1967, 1968 and 1969. Complete records were not always available for all these key tubes, due to the fact that the tubes were occasionally damaged during harvest and had to be replaced.

In loamy and sandy textured profiles it was not difficult to find a fair correlation between measured MHG and MLG values and certain profile characteristics. The upper mottling zones were easily correlated with the MHG values and gley phenomena were equally easily related to MLG values.

The correlation of measured characteristics and profile characteristics in the heavy clay profiles presented quite a problem. In particular, the MHG value was difficult to estimate, mainly due to the very dark colours of the surface horizon matrices (10YR 2/1), masking most of the colour changes and mottling. In profiles where calcium carbonate concretions were present, their presence in the first 80 cm of the profile was correlated with the MHG value. In the absence of calcium carbonate concretions, the MHG value was correlated with the maximum concentration of iron-manganese concretions. These concretions are very small and dark coloured and are easily overlooked during profile examination.

The presence of gley phenomena was again used to establish the MLG values.

In addition to these profile characteristics, field characteristics e.g. relief, stand of cane and the presence and depth of water in open drains were utilized in estimating water-table classes.

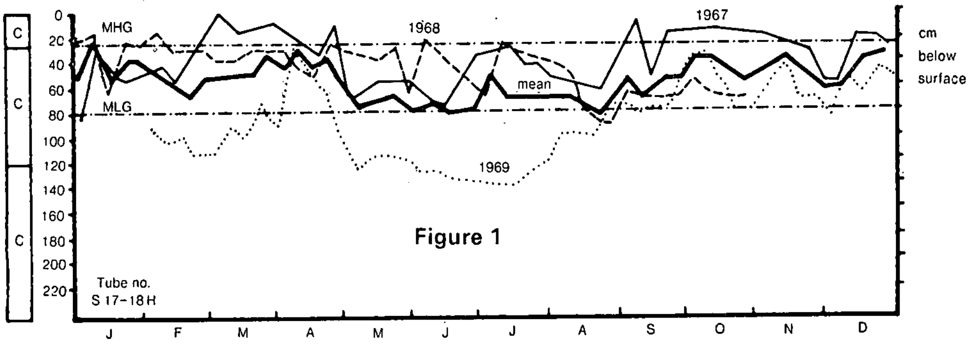

Figure 1

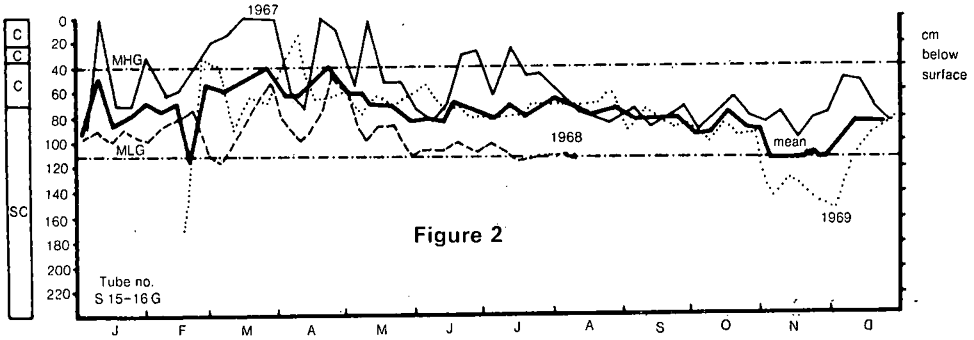

Figure 2

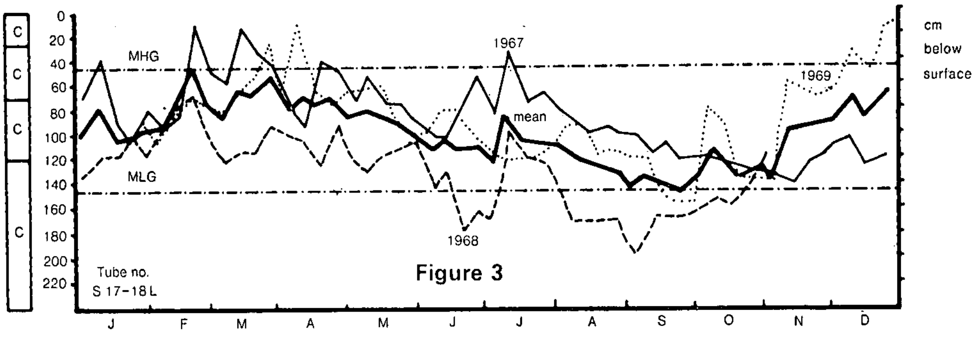

Figure 3

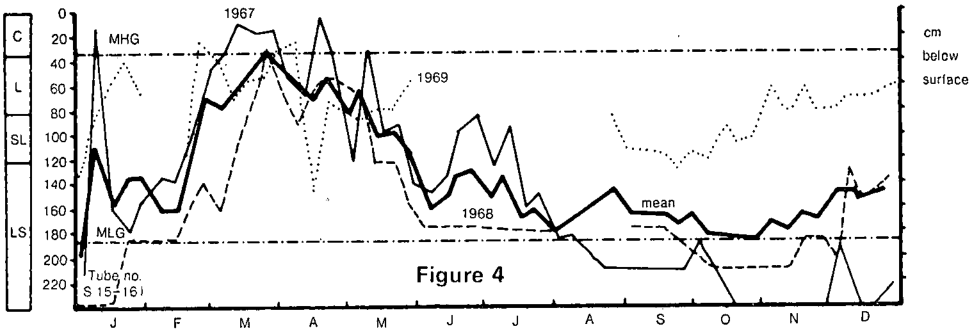

Figure 4

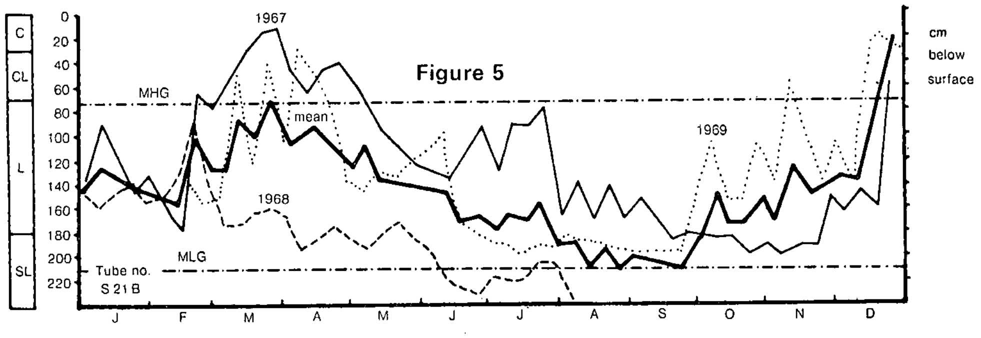

Figure 5

C = clay, SC = silty clay, CL = clay loam, L = loam, SL = sandy loam, LS = loamy sand, S = sand.

FIGURES 1-5: Time curves of the changes in the water-table and mean curves of the water-table of 5 observation tubes for the years 1967, 1968 and 1969.

It is apparent that the successful cartographical presentation of ground water level fluctuations depends on whether or not a relationship can be established between water-table classes (MHG and MLG values) and corresponding profile and field characteristics. An elaborate analysis of these relationships would therefore appear to be justified. It was found however on various occasions that no standard set of profile criteria can be established to correlate profile characteristics with MHG and MLG values for a wide variety of environmental conditions. An elaborate analysis of these relationships would not therefore further contribute to the usefulness of the developed system.

Ground water-table classes

Realizing the limitations and possible inaccuracies previously pointed out, and taking into consideration what was said when discussing sugar and cane yields and the possible hazards of salinity and alkalinity, five ground water-table classes were established. These classes are presented in Table V.

TABLE V

Five ground water-table classes for the Luabo Estate area

Classes	1	2	3	4	5
Ground water level in centimeters below surface					
MHG	<20	20–40	40–80	40–80	>80
MLG	40–80	80–100	100–160	>160	>160

During the soil mapping, the MHG and MLG values were estimated whenever a boring was carried out or a profile pit examined. Soils with equal MHG and MLG values were combined into mapping units. The boundaries of mapping units with equal MHG and MLG values generally coincide with the boundaries of existing soil mapping units. Realizing the limitations of only 3 years' data, the water-table classes were deliberately constructed in this manner.

In future years, when more data have become available and the present classes have proved their significance, the introduction of sub-classes might be considered.

Application of the map of water-table classes

The water-table classes, together with other data from the soil map, determine the suitability of the soils for growing sugar cane. The occurrence of saline ground waters with high Na^+ contents makes the subject even more important.

We are at present working on a land capability classification system for the Luabo area and some of the water-table classes presented are believed to belong to the most important 'use limitations' of the area.

Water-table class 1

These water-tables are so high that they prohibit the commercial growing of sugar cane. The hazards of salinization and accumulation of Na^+ are present in areas having contaminated ground waters. Improvement is hardly feasible.

Water-table class 2

These water-tables are so high that they interfere seriously with the favourable development of the crop. The hazards of salinization and accumulation of Na^+ are present in areas having contaminated ground waters. Improvement is hardly feasible.

Water-table class 3

These water-tables are high enough to interfere with the favourable development of the crop in case of incorrect irrigation. Care should be taken not to apply too much water from February until August. The hazards of salinization and accumulation of Na^+ exist in locations having contaminated ground waters. Improvement is feasible, though at high cost.

Water-table class 4

These water-tables are not likely to interfere with the favourable development of the crop. Peak levels are only recorded during a short time of the year and a sharp drop in level is recorded from April onwards. The hazards of salinization and accumulation of Na^+ exist in locations having contaminated ground waters. Improvement is feasible at moderate cost.

Water-table class 5

Under dry land conditions these water-tables are low enough to interfere seriously with the favourable development of the crop. During the dry season, wilting and yellowing of the cane can be frequently observed. Even under irrigation these soils suffer from drought in the dry season, due to low water storage capacities and high permeabilities. The hazards of salinization and accumulation of Na^+ are absent.

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REFERENCES

1. Gardner, W. R. and Fireman, M., 1958. Laboratory studies of evapotranspiration from soil columns in the presence of a water-table. *Soil Sci.* 85/244-249.
2. Gosnell, J. M., 1971. Effects of water-table on cane growth. Rhodesia Sugar Association Experiment Station. *Sugar News* No. 7.
3. Heesen, H. C. van and Westerveld, G. J. W., 1966. Karakterisering van het grondwaterstandsverloop op de bodemkaart. *Cultuurtechnisch Tijdschrift*, 5 (1966) 5, pp. 189-207.
4. Heesen, H. C. van, 1970. Presentation of the seasonal fluctuation of the water-table on soil maps. *Geoderma*, 4.
5. Lapperre, P. E., 1969. Soil Investigations Luabo Estate. *Sena Sugar Estates Limited, London.*
6. Lapperre, P. E., 1971. Zambesi Delta Soils for the production of sugar cane. Their classification, morphology and chemical and physical properties. *Agronomia Moçambicana*, 5 (4) 1971.

7. Marshall, T. J., 1959. Relations between water and soil. *Commonwealth Bureau of Soils, Harpenden, Tech. Comm. No.* 50.
8. Soil Survey Institute of The Netherlands (Stiboka) 1968. Het in de winter verzamelen van gegevens ten behoeve van de Gt kartering. *Mededeling* No. 2, *Afdeling Hydrologie en Cultuurtechniek.*
9. Soil Survey Institute of The Netherlands (Stiboka) 1968. De grondwatertrappenkaart. *Mededeling* No. 4, *Afdeling Hydrologie en Cultuurtechniek.*
10. Talsma, T., 1963. The control of saline ground water. *Meded. Landbouw Hoogeschool, Wageningen.* 63 (10).
11. Wilkins, R. A. and Athesian, K. H., 1965. Relationship between ground water, salinity and sugar cane at Rose Hall Estate. *Proc. 12th Int. Sug. Tech. Cong., Puerto Rico.*
12. United States Department of Agriculture 1960. Comprehensive System of Soil Classification, 7th Approximation. *U.S. Department of Agriculture.*
13. United States Department of Agriculture 1967. Comprehensive System of Soil Classification, 7th Approximation. Supplement to Soil Classification System. *U.S. Department of Agriculture.*