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Assessment of Cane Yields on Well-drained Ferralsols in the Sugar-cane Estate of Central Cameroon

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Summary

The potential yields of irrigated and of rainfed sugar-cane on three ferrallitic soil series, well represented in the Nkoteng sugar-cane estate of Central Cameroon, are estimated following different methods. The potential yield of irrigated sugar-cane is estimated from the total maximum evapotranspiration during the crop cycle. The potential yield of rainfed sugar-cane is estimated following two methods for the establishment of a water balance and for the determination of a yield reduction as a result of a water deficit. The calculated potential yields are higher than the observed ones. The yield reduction due to rainfed cropping can mainly be attributed to water shortage during the late yield formation and the ripening periods. A supplementary yield decline is due to a combined action of an acid soil reaction, a possible Al-toxicity, a low base saturation, an inadequate CEC, organic matter content and P-availability, which may adequately explain the actual yield level.

Résumé

Les rendements potentiels en culture irriguée et pluviale de la canne à sucre sont estimés par différentes méthodes sur trois séries de sols ferralitiques représentatifs du périmètre sucrier de Nkoteng, Centre Cameroun. Le rendement potentiel de la canne à sucre sous irrigation est estimé à partir de l'évapotranspiration totale maximale pendant le cycle de la culture. Le rendement potentiel en culture pluviale est estimé à partir du bilan hydrique et de la détermination de la réduction de rendement comme résultante du déficit en eau. Les rendements potentiels calculés sont plus élevés que ceux observés. La réduction de rendement en culture pluviale est principalement attribuée à une insuffisance d'eau pendant les derniers stades correspondant à la formation du produit récolté et de sa maturation. Une réduction supplémentaire de rendement est due à l'action combinée de la réaction acide du sol, la toxicité aluminique éventuelle, une faible saturation en bases, une CEC inadéquate, une faible teneur en matière organique et en phosphore assimilable, facteurs qui permettent d'expliquer le niveau de rendement actuel.

Introduction

Sugar-cane (*Saccharum officinarum* L.) is a C_4-crop (14), and consequently gives higher yields with an increasing incident solar radiation. Cane production is further known to be directly proportional to the water transpired (3). Good yields of sugar-cane are therefore obtained in conditions which ensure an adequate supply of water and sunshine. Optimal conditions are met in a climate which permits sprouting of stem cuttings at mean daily temperatures of 32 to 38°C, and which allows cane growth at mean daily temperatures of 22 to 30°C (8). High maximum and low minimum temperatures should be absent. Following a long, warm and humid vegetative period, the ripening period should be relatively cool (mean daily temperatures in the range of 10 to 20°C with a high daily thermic amplitude), sunny and dry (20). Rainfall should be sufficient to guarantee adequate and constant water supply. Rainfed cane, on well-drained soils with a good water retention capacity, requires an evenly distributed rainfall during emergence, vegetative and yield formation periods with a minimum of 100 to 120 mm per month or 1,200 to 1,500 mm annual rainfall (11).

The Nkoteng sugar-cane estate is situated near the limit of the equatorial forests in the south and the savannas in the north, and is located at 120 km north of Yaoundé and at 35 km south-west of Nanga-Eboko, in the Haute Sanaga, Central Cameroon. The studied area covers about 11,200 ha and is limited in the north and the south by the parallels of 4°31' and 4°22' latitude N, and in the west and the east by 12°00' and 12°12' longitude E. The estate is part of the large and gently undulating peneplain with shallow slopes, which occupies the central southern part of Cameroon. The monotonous relief of the peneplain, which is stretched at an altitude of 600 to 630 m above mean sea-level, is interrupted by some mountain ridges which reach 850-1,050 m. The geological substratum consists of micaschist, "embréchite" and quartzites of the ancient base complex (9).

The present climate of the area is classified as "continental sub-equatorial" because of the presence of two clearly separated rainy seasons and the low minima of the relative air humidity. The periods of minimum rain-

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Table 1
Meteorological data at the Nkoteng surgar-cane estate

CHARACTERISTICS	J	F	M	A	M	J	J	A	S	O	N	D	MEAN	TOTAL
Temperature (°C)														
- mean	24.3	25.3	25.5	25.0	24.5	23.8	23.1	23.3	23.7	23.7	24.2	24.4	24.2	-
- mean max.	30.0	31.5	31.1	30.1	29.3	28.0	26.8	27.1	28.1	28.3	29.2	29.7	29.1	-
- mean min.	18.6	19.1	19.9	19.8	19.7	19.5	19.4	19.3	19.1	19.1	19.1	19.1	19.3	-
Sunshine hours	178	172	154	151	152	116	85	84	100	122	156	175	137	1,645
Relative humidity (%)														
- mean	68.5	64.5	71.7	77.0	83.0	81.3	83.7	83.7	80.0	81.0	77.3	72.6	77.0	-
- mean max.	95.0	93.0	95.0	96.2	97.2	96.3	96.7	96.7	96.3	97.3	96.6	96.3	96.1	-
- mean min.	41.7	35.5	48.0	52.5	68.5	65.3	70.0	70.0	65.0	64.0	57.0	49.0	57.2	-
Rainfall (mm)	24	40	114	177	212	153	93	127	269	303	103	26	-	1,641
Rainfall days														
- mean	1	3	7	12	13	9	6	9	14	18	5	2	-	99
- max.	2	5	10	13	17	12	10	12	17	24	11	5	-	138
- min.	0	1	4	10	11	7	4	5	11	15	2	0	-	70
Mean wind velocity (m/s)														
(at 4 m above ground level)	2.5	2.4	2.5	2.3	2.3	2.4	2.3	2.5	2.3	2.4	2.3	2.2	2.4	-

fall constitute the dry season and occur from December to February and during July and August. The periods of maximum rainfall are observed from March until June and from September until November. The annual rainfall varies between 1,450 and 1,700 mm. About 130 raindays are observed annually. The mean monthly temperature range is 23 to 25°C. The annual total of sunshine hours is 1,700.

In this study the potential yields of irrigated and rainfed sugar-cane on three major soil series of the region are estimated following different methods. The differences between calculated and observed yields are explained and proposals are made for yield improvement.

Material and methods

Meteorological data

The meteorological data for the Nkoteng sugar-cane estate have been inferred from the observations at the meteorological stations of Nanga-Eboko, Mbandjock and Yaoundé. The data are represented in table 1.

Soil data

Three well-drained ferrallitic soil series, well represented in the Nkoteng estate, were selected for further study. They occur un roughly 7,400 ha (9). Brief description of these soil series is as follows:

(a) *Simbane Series:* this soil series is observed on the topflats and slopes in a gently undulating landscape and occupies 2,900 ha. Simbane series consists of well-drained, dark red, clayey, deep soils developed on "embréchite" and/or on micashist. The series is classified as "Sols Ferrallitiques fortement désaturés, typiques, modaux sur embréchite" (5), as Rhodic Ferralsols (10) and as clayey, kaolinitic, isohyperthermic Rhodic Kandiustults (16);

(b) *Nkoteng Series:* the soils belonging to this series are observed on 3,300 ha. Their characteristics are similar to those of Simbane series with the exception of a more sandy texture and dark reddish brown colours in the upper horizons because of an impoverishment process. They occupy an identical topographical position and have developed from the same parent rock as Simbane series. They are classified as "Sols Ferrallitiques moyennement désaturés, typiques, modaux sur micaschist" (5), as Rhodic Ferralsols (10) and as clayey, kaolinitic, isohyperthermic, Rhodic Haplustox (16);

(c) *Ngamba Series:* this series are observed near quartzite hills which dominate the region and occupies a total of 1,200 ha. Ngamba series are well to excessively drained, strong brown soils with a sandy loam texture near the surface and a sandy clay loam to clay texture at greater depth. They are often rejuvenated and have a variable depth (3 to 4 m). These soils are classified as "Sols Ferrallitiques moyennement désaturés, moyennement rajeunis avec érosion et remaniement sur quartzite" (5), as Orthic Ferralsols (10) and as clayey, kaolinitic, isohyperthermic Typic Kandiustults (16).

The physical and chemical characteristics of the above described soil series are represented in tables 2 and 3, respectively. The analysis were carried out at the Soil Science Laboratory of the National Advanced School of Agriculture in Yaoundé (1). The calculated amount of available soil water up to 1 m depth in Simbane, Nkoteng and Ngamba series is 115.4, 108.7 and 106.0 mm, respectively.

Reference and potential crop evapotranspiration

The reference evapotranspiration (ETo) has been calculated according to the modified Penman method (12). The potential or maximum crop evapotranspiration (ETc) is calculated by multiplication of ETo with a crop coefficient Kc. This crop coefficient relates ETc of sugar-cane to ETo for different crop growth stages, as a function of minimum relative humidity and wind velocity (8). The crop growth stages, their duration and Kc values, as used in the calculations, are given in table 4. The Kc values during the growth stages 2 and 4 are determined by linear interpolation between the previous and following Kc values.

Table 2
Some physical characteristics of the different soil series

Series	Hor.	Depth (cm)	Munsell colour		Granulometric composition (%)			Structure (1)	Root density (2)	Bulk density (g cm^{-3})	Total porosity (%)	Available water (% on dry weight basis)
			Fresh	Dry	Clay	Silt	Sand					
Simbane	A	0-12	5 YR 3/3	5 YR 5/3	27.8	14.5	57.7	++	+++	1.3	51	4.7
	BA	12-30	2.5 YR 3/4	2.5 YR 5/4	32.7	11.7	55.6	++	+++	1.4	46	6.4
	B1	30-95	2.5 YR 3/6	2.5 YR 5/4	49.9	10.1	40.0	+	+	1.5	40	8.7
	B2	95-150	10 R 3/6	40 R 4/6	53.8	8.5	37.7	+	+	1.5	39	8.9
	B3	150-190	10 R 3/6	10 R 4/6	50.3	11.4	38.3	+	(+)	1.5	55	9.2
Nkoteng	A	0-13	7.5 YR 3/2	7.5 YR 4/2	23.4	11.4	65.2	++	+++	1.3	64	3.6
	BA	13-30	5 YR 3/4	5 YR 4/4	28.9	10.0	61.1	++	++	1.5	41	6.4
	B1	30-60	2.5 YR 3/6	2.5 YR 4/6	33.0	18.6	48.3	++	+	1.5	37	6.7
	B2	60-120	2.5 YR 3/6	2.5 YR 4/6	51.7	7.1	41.2	+	+	1.5	50	9.3
	B3	120-190	2.5 YR 3/6	2.5 YR 4/6	49.2	10.6	40.2	+	(+)	1.6	39	9.5
Ngamba	A	0-12	10 YR 3/2	10 YR 5/2	16.2	9.0	74.8	++	+++	1.2	37	4.1
	BA	12-27	10 YR 4/4	40 YR 5/4	23.0	9.8	67.2	++	++	1.3	50	5.8
	B1	27-74	7.5 YR 5/6	7.5 YR 6/6	42.8	9.4	47.8	++	+	1.4	48	7.6
	B2	74-140	7.5 YR 5/6	7.5 YR 6/6	40.1	6.4	53.5	+	(+)	1.5	51	10.0
	B3	14-200	7.5 YR 5/6	7.5 YR 6/6	39.7	7.0	53.3	+	(+)	1.5	39	11.6

(1) ++ : moderately developed; +: weakly developed
(2) +++ : abundant; ++: many; +: few; (+): very few

Table 3
Some chemical characteristics of the different soil series

Series	Horizon	Depth	Acidity (pH)		Organic matter			Exchangeable cations (cmol(+)kg^{-1})			Ca/Mg/K ratio	CEC (cmol(+)kg^{-1})	Base saturation (%)	Available phosphorus (ppm P_2O_5)
			H_2O	KCl	O.C. (%)	N (‰)	C/N	Ca	Mg	K				
Simbane	A	0-12	5.1	4.0	2.1	1.3	15	0.76	0.54	0.13	53/38/9	8.80	16	8.4
	BA	12-30	5.0	4.1	1.3	0.8	16	0.72	0.38	0.04	63/33/4	6.00	19	7.0
	B1	30-95	4.8	4.3	0.6	0.5	12	0.50	0.30	0.06	58/35/7	5.12	17	6.2
	B2	95-150	4.8	4.6	0.5	0.3	15	0.68	0.22	0.08	69/23/8	4.24	23	6.2
	B3	150-190	4.7	4.6	0.3	0.3	10	0.74	0.46	0.06	59/36/5	3.20	39	3.6
Nkoteng	A	0-13	4.6	4.2	1.1	0.8	13	0.84	0.56	0.16	54/36/10	5.36	29	6.6
	BA	13-30	4.4	4.1	0.7	0.7	10	0.56	0.40	0.09	53/38/9	3.84	27	8.0
	B1	30-60	4.4	4.2	0.5	0.8	7	0.68	0.56	0.06	52/43/5	4.08	32	6.2
	B2	60-120	4.5	4.4	0.5	0.6	9	0.60	0.34	0.06	60/34/6	2.96	34	2.8
	B3	120-190	4.6	4.5.	0.3	0.4	9	0.40	0.34	0.05	51/43/6	3.76	21	3.4
Ngamba	A	0-12	4.5	4.1	0.7	0.6	12	0.48	0.38	0.10	50/40/10	3.37	28	7.4
	BA	12-27	4.3	4.0	0.5	0.5	10	0.46	0.38	0.09	49/41/10	3.52	26	5.2
	B1	27-74	4.4	4.1	0.5	0.5	10	0.70	0.58	0.10	51/42/7	4.80	29	8.0
	B2	74-140	4.5	4.3	0.4	0.4	10	0.78	0.46	0.07	60/35/5	4.56	29	6.4
	B3	140-200	4.6	4.5	0.2	0.3	9	0.80	0.46	0.05	61/35/4	4.32	30	3.4

Table 4
Crop growth stages, their duration and corresponding Kc-value (8)

Crop growth stage		Duration (days)	Kc
- planting to 0.25 full canopy	[1]	30	0.48
- 0.25 full canopy to full canopy	[2]	90	
- peak use	[3]	180	1.09
- early senescence and ripening	[4]	60	
- harvest	[5]		0.67

Yield reduction as a result of a water deficit

- *Method 1a:* a water deficit is obtained when the difference between the effective precipitation (EP) and ETc is negative in a decade during the crop cycle. EP is calculated according to the method of the USDA Soil Conservation Service (7,19), using data of mean monthly rainfall, mean monthly consumptive water use and depth of available water in the root zone. Root development is assumed to increase according to a sigmoid function in depth with time (13). Maximum root development is supposed to be reached at the time cane has developed full canopy.

Normal decade values of effective precipitation, evapotranspiration and rainfall are obtained by parabolic interpolation from monthly data (13).

The relative evapotranspiration is calculated as the sum of EP for each decade during the crop cycle divided by the sum of ETc for each decade, and is expressed as a fraction. The relative yield reduction (1-Ya/Ym) in which Ya stands for actual yield and Ym for maximum yield, is considered equal to the relative evapotranspiration deficit (1-EP/ETc).

- *Method 1b:* the crop cycle of sugar-cane can be subdivided into subsequent crop growth periods: the emergence and establishment period, the vegetative period, the yield formation period and the ripening period. An evapotranspiration deficit during each of these growth periods has a different effect on yield. The relative evapotranspiration is calculated as in method 1a, but for each of the growth periods instead of for the total growing cycle. The effect of a relative evapotranspiration deficit (1-EP/ETc) on a relative yield decrease (1-Ya/Ym) is quantified through the yield response factor (Ky) for each growth period:

$$(1\text{-}Ya/Ym) = Ky(1\text{-}EP/ETc)$$

The relative yield at the end of the crop cycle is calculated as the product of the relative yields obtained for each of the crop growth periods. The crop growth periods, their duration and corresponding Ky-value adopted in the calculations are given in table 5.

Table 5
Crop growth periods, their duration and corresponding Ky-value (8)

Crop growth period		Duration (days)	Ky
- emergence and establishment	[0]	20	0.75
- vegetative period	[1]	190	0.75
- yield formation period	[3]	90	0.50
- ripening period	[4]	60	0.10

- *Method 2a:* in the second calculation procedure the actual crop evapotranspiration (ETa) is determined using a water balance model, valid for freely drained homogenous soils without groundwater supply. It is assumed that ETa is equal to ETc until a fraction (p) of the total available soil water (Sa) over the rooting depth (D) has been depleted. Under this assumption the following relationship holds (15):

$$ETa = ETc = \frac{-d(St.D)}{dt} \text{ if } St.D \geq (1-p)Sa.D$$

with
Sa.D = total available soil water over the rooting depth D; and
St.D = available soil water at time t over the rooting depth D.
Beyond the depletion of the fraction (p) of the total available soil water (Sa.D), ETa will fall below ETc and ETa will depend on the remaining soil water and on ETc. This relationship can be written as (15):

$$ETa < ETc \text{ and } ETa = \frac{-d(St.D)}{dt} = \frac{St.D \times Etc}{(1-p)Sa.D} \text{ if } St.D < (1-p)Sa.D$$

Integration of the above equation over the time period from t1 to t2 yields the following equation (6):

$$ETa = (St.D)_{t1} - e^{[\ln(St.D)_{t1} \frac{-ETc.(t2-t1)}{(1-p)Sa.D)}]}$$

The relative evapotranspiration is calculated as the sum of ETa of each decade during the crop cycle divided by the sum of ETc of each decade during the crop cycle. The relative yield reduction (1-Ya/Ym) is considered equal to the relative evapotranspiration deficit (1-ETa/ETm).

- *Method 2b:* ETa is calculated following the crop water balance as under method 2a. The relative evapotranspiration is calculated for each individual growth period as the sum of ETa divided by the sum of ETc during that growth period. The effect of a relative evapotranspiration deficit (1-ETa/ETc) during a crop growth period on the relative yield decrease (1-Ya/Ym) is quantified through Ky (8). The relative yield at the end of the crop is calculated as in method 1b.

Results and discussion

Potential irrigated yield

The vegetative growth and yield of sugar-cane is directly proportional to the amount of water transpired by the crop (11). For a plant or first ratoon crop the yield of fresh cane is estimated at 10 ± 2 tons ha^{-1} per dm of water consumed by the crop. A plant or first ratoon crop, grown without water deficit, produces 0.6 to 1.0 kg sucrose m^{-3} of water consumed (8). ETc calculated for the total crop cycle of a 12 month plant or first ratoon crop at Nkoteng, is 1,258 mm of water (tables 6 and 7). According to the above relationship, the fresh cane yield of the crop, adequately supplied with water, can be estimated at 100.6 to 151.0 tons ha^{-1} with an average value of 124.8 tons ha^{-1}. The sucrose yield of the irrigated crop is estimated at 7.5 to 12.6 tons ha^{-1} with 10.0 tons ha^{-1} as an average value.

Table 6
Calculated normal decade values of precipitation (P), crop reference evapotranspiration (ETo) and determination of the growing period

Decade	Number	P (mm)	ETo (mm)	Season[1]	
JAN 1	1	7.3	41.2	0	0
JAN 2	2	7.8	42.0	0	0
JAN 3	3	8.9	42.6	0	0
FEB 1	4	8.7	42.7	0	0
FEB 2	5	12.6	43.2	0	0
FEB 3	6	18.7	43.8	0	0
MAR 1	7	30.3	45.4	1	0
MAR 2	8	38.1	45.4	1	0
MAR 3	9	45.5	44.6	1	1
APR 1	10	53.4	41.9	1	1
APR 2	11	59.3	40.7	1	1
APR 3	12	64.3	39.6	1	1
MAY 1	13	71.4	39.1	1	1
MAY 2	14	71.8	38.1	1	1
MAY 3	15	68.8	37.0	1	1
JUN 1	16	57.6	35.2	1	1
JUN 2	17	51.0	34.2	1	1
JUN 3	18	44.4	33.4	1	1
JUL 1	19	33.0	32.7	1	1
JUL 2	20	29.8	32.5	1	0
JUL 3	21	30.1	32.6	1	0
AUG 1	22	33.2	33.5	1	0
AUG 2	23	41.0	34.0	1	1
AUG 3	24	52.8	34.6	1	1
SEP 1	25	79.2	35.2	1	1
SEP 2	26	91.0	35.8	1	1
SEP 3	27	98.8	36.3	1	1
OCT 1	28	108.8	36.9	1	1
OCT 2	29	103.9	37.3	1	1
OCT 3	30	90.3	37.5	1	1
NOV 1	31	50.5	37.1	1	1
NOV 2	32	32.8	37.3	1	0
NOV 3	33	19.7	37.7	1	0
DEC 1	34	13.5	38.4	1	0
DEC 2	35	7.7	39.1	1	0
DEC 3	36	4.7	39.9	0	0

(1) Length of the growing season (FAO): 290 days
0 0: non-growing season
1 0: growing season, non-humid decade
1 1: growing season, humid decade

Table 7
Decade values of the maximum crop evapotranspiration (ETc), the deficit (DEF), or excess (EXC.) with regard to observed precipitation, the effective precipitation (EP), the deficit with regard to effective precipitation (method 1a); the decade values of the actual evapotranspiration (ETa) and the root zone available moisture content (St.D)

			Method 1		Method 2	
Decade number	ETc (mm)	DEF. or EXC (mm)	EP (mm)	DEF. (mm)	ETa (mm)	St.D (mm)
7	21.8	8.5	12.3	-9.5	21.8	14.3
8	21.8	16.4	14.9	-6.8	21.8	24.0
9	21.4	24.1	15.7	-5.7	21.4	31.3
10	21.7	31.7	17.0	-4.7	21.7	40.5
11	23.8	35.6	19.9	-3.8	23.8	51.4
12	25.8	38.4	22.9	-2.9	25.8	63.2
13	28.2	43.2	26.0	-2.1	28.2	75.1
14	30.0	41.8	28.7	-1.3	30.0	86.0
15	31.7	37.1	30.8	-0.9	31.7	95.3
16	32.6	25.0	32.2	-0.4	32.6	102.7
17	33.9	17.1	33.0	-1.0	33.9	108.3
18	35.4	9.0	29.8	-5.6	35.4	112.3
19	35.7	-2.6	23.2	-12.5	35.7	109.7
20	35.4	-5.6	21.1	-14.3	35.4	104.1
21	35.6	-5.4	21.3	-14.2	35.6	98.7
22	36.5	-3.3	23.4	-13.1	36.5	95.4
23	37.1	3.9	28.2	-8.9	37.1	99.3
24	37.7	15.1	35.0	-2.7	37.7	114.4
25	38.4	40.8	38.4	0.0	38.4	115.4
26	39.0	52.0	39.0	0.0	39.0	115.4
27	39.5	59.2	39.5	0.0	39.5	115.4
28	40.3	68.5	40.3	0.0	40.3	115.4
29	40.7	63.2	40.7	0.0	40.7	115.4
30	40.9	49.5	40.9	0.0	40.9	115.4
31	40.4	10.1	34.3	-6.1	40.4	115.4
32	40.7	-7.9	23.7	-16.9	40.7	107.5
33	41.1	-21.4	14.9	-26.2	41.1	86.1
34	41.9	-28.3	10.5	-31.4	41.9	57.8
35	42.6	-34.9	6.1	-36.5	38.1	27.5
36	43.5	-38.8	3.8	-39.7	20.4	11.8
1	43.3	-36.0	5.8	-37.5	12.1	7.1
2	41.2	-33.4	6.1	-35.1	9.3	5.5
3	38.8	-29.9	6.9	-31.9	9.0	5.4
4	35.9	-27.3	6.6	-29.3	8.8	5.3
5	33.3	-20.7	9.3	-24.0	11.1	6.7
6	30.7	-12.0	13.3	-17.4	15.8	9.6
TOTAL	1,258.2	-	815.6	-442.6	1,073,4	-

Tabel 8
Relative yields for each of the crop growth periods and for the total sugar-cane crop cycle on Simbane series according to the methods 1b and 2b

Crop growth period		Relative yield (%) Method 1b	Method 2b
- emergency and establishment	[0]	88	100
- vegetative period	[1]	100	100
- yield formation period	[3]	78	96
- ripening period	[4]	92	93
Total crop cycle		63	89

Table 9
Relative yields (%) on Simbane, Nkoteng and Ngamba series

Calculation method	Relative yield (%) Simbane	Nkoteng	Ngamba
Method 1			
1a	65	64	64
1b	63	63	62
Method 2			
2a	85	85	85
2b	89	88	88

Potential rainfed yield

Sugar-cane, grown at the Nkoteng estate, is not irrigated and suffers from water stress during some period in the crop cycle. Table 7 gives, for sugar-cane produced on Simbane series, the values of ETc, the deficit or excess of water with regard to observed precipitation, the EP obtained according to method 1, the water deficit calculated from the difference (EP-ETc), ETa and St.D obtained from the water balance following method 2 for each decade during the crop cycle and for the total crop cycle. The values indicate that the evaluation of the water status using EP against ETc (method 1) is more severe than the evaluation using a calculated ETa against ETc (method 2). If the results of both methods are considered as extreme values that can be obtained from a same production situation, the following observations can be made with regard to the water availability of a 12 month plant or first ratoon crop:

- in average meteorological conditions, water supply is satisfactory during emergence, establishment and early vegetative period (tillering). Only a slight water deficit may be observed in these periods. As the rainfall return-period is relatively short (3 to 4 days), germination is expected to be early and uniform, and to yield a satisfactory number of tillers;
- a slight deficit is possible during most of the late vegetative period (stem elongation) and the early yield formation period. As a result of the close relationship between stalk elongation and water use, a temporary reduction in the length of the cane internodes and of the total cane height is possible. Part of the height of the cane can, however, be regained in the yield formation period; and
- in the last part of the late yield formation period and during the ripening period, a distinct water deficit is observed. Although a moderate water deficit in these periods is known to bring the crop to maturity by reducing the rate of vegetative growth, dehydrating the cane and forcing the conversion of total sugars to recoverable sucrose, the observed deficit is too strong and a yield decrease will result.

Table 8 gives, for sugar-cane grown on Simbane series, the relative yield reduction and relative yield for each of the crop growth periods and for the total crop cycle as calculated using methods 1b and 2b. These results show that the yield reduction due to rainfed cropping can mainly be attributed to water shortage during the late yield formation and the ripening periods. Table 9 gives the relative yields on Simbane, Nkoteng and Ngamba series obtained from methods 1 and 2, with and without the use of a crop response factor (Ky). The results in table 9 show that both methods lead to distinctly different results. Within each method, the use of Ky in the calculations does in this particular case not significantly alter the results. The difference in available soil water reserve between the three soils does not lead to marked differences in yield.

According to the above calculations the potential rainfed sugar-cane yield is estimated to be in the range of 62 to 89% of the potential irrigated yield, or between 78 and 112 tons of fresh cane ha^{-1} and 6.3 to 9.0 tons sucrose ha^{-1}.

Actual rainfed yield

The potential rainfed yield is however still higher than the actual rainfed yield. During the production period 1979/1980 an average yield of 64.9 tons fresh cane ha^{-1} was recorded. The sucrose content was 11.7% and resulted, with 8.2% sucrose recovery in a yield of 5.3 tons sucrose ha^{-1} (4).
The unfavourable effect on yield of some soil characteristics is thought responsible for a supplementary yield decline and may adequately explain the actual yield level. Although sugar-cane has a large tolerance with regard to the pH range of the soil (pH 4.0-8.5); increasing yield reductions are observed towards the extremes (3). The optimum pH for sugar-cane is 6.5. Along with a very slightly acid soil reaction, the sugarcane crop prefers a base saturation of more than 50% (18). In Simbane series the soil reaction is slightly acid (pH 5.1) in the surface layer and acid (pH 4.7) at greater depth. In both Nkoteng and Ngamba series the soil reaction is acid to very acid with pH(H_2O) values in the range of 4.3-4.6. The saturation of the exchange complex with basic cations is low. The weighted average base saturation is the upper 30 cm of soil is 18, 28 and 27% for Simbane, Nkoteng and Ngamba series, respectively. These values, along with the low pH, suggest a rather large and toxic quantity of exchangeable aluminium, which may be responsible for the restricted root development as suggested in table 2.

The optimal mutual ratio of the basic cations of Ca, Mg and K is 76/18/6 (18). The observed ratios in the three soil series indicate slightly lower amounts of Ca and proportionally higher amounts of Mg with regard to the optimum. As both cations are largely interexchangeable, the ratios can be considered to be nearly optimal. Large deficiencies are observed with regard to the absolute amounts of basic cations required for a good sugar-cane crop. A minimum requirement of 3 cmol(+) Ca kg^{-1} soil in the surface layer of 0 to 30 cm has been suggested (17,3). Considering the optimal cation ratio and a base saturation of 50%, equally 0.71 cmol(+) Mg and 0.24 cmol(+) K kg^{-1} of soil are required along with a minimum CEC of 7.9 cmol(+) kg^{-1}. The weighted average CEC-values over 0-30 cm of soil are 7.12, 4.50 and 3.59 cmol(+) kg^{-1} soil for Simbane, Nkoteng and Ngamba series, respectively. The absolute amounts of basic cations are largely below the minimum required amounts.

For optimal sugar-cane production the soil should contain 2.5% of organic matter. In Simbane series the weighted average organic matter content of the surface layer (0-30 cm) is 2.8% and adequate. Inadequate amounts of organic matter are found in Nkoteng and Ngamba series, which have 1.5 and 1.0% of organic matter only. A response to P-fertilizer application is likely when the amount of available phosphorus (Truog) is less than 25 ppm (17,3). In the three soil series the available phosphorus is definitely lower than required (table 3). P-application should satisfy the P-fixing capacity of the soils and should include the maintenance application. Field experiments at Mbandjock have permitted to estimate the required quantity at 800 kg P_2O_5 ha^{-1} single superphosphate at 18% for a yield of 80 tons of cane ha^{-1} of variety B41-227 (2).

The combined action of an acid soil reaction, a possible aluminium toxicity, a low base saturation, an inadequate CEC, organic matter content and P-availability may account for a further yield reduction of 15 to 40% with regard to the potential rainfed yield. On Simbane series a considerable yield upto the level of the potential rainfed yield can be obtained with an increase of the organic matter content and CEC using filter mud and molass applications, an increase of the absolute amounts of Ca, Mg and K up till the required minimum levels, and an adequate P-supply. On Nkoteng and Ngamba series the yield increase following similar improvement measures may not reach the potential level due to their low inherent fertility. An additional yield increase may be obtained with moderate irrigation in the drying-off period in order to restrict the drying out of the soil and to lower the soil surface and air temperature.

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52ste Internationaal Symposium over Fytofarmacie en Fytiatrie

Zal plaats vinden op dinsdag 9 mei 2000 aan de Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent (België).

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De voorgestelde mededelingen zullen gepubliceerd worden in de "Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent".

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