Late season sugarcane performance as affected by soil water regime at the yield formation stage on commercial farms in northern Ivory Coast

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Abstract

A field trial was carried out in Ferké 2 Sugar mill located in northern Ivory Coast, in order to study sugarcane growth and yield response to deficit irrigation imposed at the yield formation stage. The crop used was a first ratoon Co957, a non flowering late season sugarcane variety. The experiment was completely randomized following a one-factor design with 4 water deficit treatments in 3 replicates. It came out that the optimum water deficit treatment was 20 %, i.e., 80 % of crop water requirements were satisfied through irrigation. That treatment gave 7.9 kg cane/m^3 or 0.98 kg sugar/m^3 as irrigation water use efficiency. More over, relatively low crop growth as well as low yields were obtained as a result of an intensive and persistent dry season occurring over the yield formation stage. Because of prevailing climatic conditions, cane juice quality measured was particularly high on Co 957 which used to be a moderate performing variety in Ferké 2 sugar mill.

Key Words

Deficit irrigation, yield formation, stalk growth, cane yield, Ivory Coast

Introduction

Previous studies carried out on commercial sugarcane plantations of Ferké 1 as well as Ferké 2 mills in northern Ivory Coast showed that water was the main yield limiting factor (Péné *et al*., 1997; Péné and Tuo, 1996). Water is seen as a complex factor as its availability is climate and soil texture dependent (Frère and Popov, 1987). To mitigate rainfall hazards and better meet sugarcane crop water requirements, sound irrigation investments are being made every year by the SUCAF-CI company. Nevertheless, sugar produced by the company through 2 mills at yearly basis is still strongly dependent on rainfall patterns. That's why water management efforts for a better impact of irrigation on cane yields are a major concern. Moreover, it was shown that late season sugarcane stalk growth and yield response to irrigation on Ivorian sugar mills was quiet low for most varieties under cultivation like Co 957, Fr 8069, R 570 (Péné and Kéhé, 2005; Péné and Koulibaly, 2007; Péné, 1999). The study objective was to impose deficit irrigation over the yield formation stage of late season sugarcane in order to increase crop water use efficiency.

Material and methods

Site characteristics

The study was carried out on a commercial field of Ferké 2 sugar mill in northern Ivory Coast which is located 40 km away from the city of Ferkessédougou (09°35'N, 05°12W, 330 m ASL). The prevailing climate is tropical dry with a unimodal rainfall pattern averaging 1200 mm/year. The 7-month rainy season takes place from April to October, August and September being highly wetted with a total rainfall of 500-600 mm. The 5-month dry season starting from November to March, is marked by a hot as well as dry wind originating from Sahara, namely the *harmattan* (or northern trade wind) which prevails from November to January with the highest magnitude of daily temperatures (+10-20 °C). The vegetation is Guinea savannah with some thin rain forests along waterways. Soils are mainly ferralsols with occasionally alluvial soils or hydromorphic soils in valley bottoms as well as in uplands where water infiltration is limited by impermeable layers. The Ferké 2 sugar mill covers a total cultivated land surface of 8000 ha which are mainly under sprinkler as well as drip irrigation.

Sugarcane crop

The cane variety investigated (Co 957) is widely grown in Ferké 2 sugar mill as a late season crop over about 40 % of total cultivated land (2300 ha). Only the first ratoon cane, harvested on March 20, 2007, was investigated. The plant crop was harvested on March 17, 2006.

Over a late season cane crop, the irrigation management involves 2 watering campaigns. The first one started at early growth stage and ended at the stem elongation stage in mid July. The second one took place at the yield formation stage which started from early November 2006 to late February 2007, i.e., approximately three weeks prior to harvest.

Experimental design

The study was laid out on the 10-numbered commercial field of 22 ha. Apart from the yield formation stage, irrigation water was applied uniformly in the field following routine management practices. Four watering regimes were imposed over the yield formation stage as follows: T0: zero water deficit at yield formation (control); T20: 20 % water deficit at yield formation; T80: 80 % water deficit at yield formation; T100: 100 % water deficit at yield formation (control). The experiment was laid out following a RCB with 4 irrigation treatments in 3 replicates. Every plot was 1 ha area, i.e., 16 cane rows of 432 m in length with 1.5 m row spacing. Stalk elongation measurements were made twice a month (every two weeks) over a sample of 10 canes randomly chosen within all individual plots. All key agronomic factors, namely fertilization, weeding and soil tillage, were kept constant except for soil water regimes at the yield formation stage. Fertiliser rates applied in the field at early crop growth stage were 300 kg/ha of urea (46 % N), 100 kg/ha of super phosphate (45 % P_2O_5) and 350 kg/ha of potassium chloride (60 % K_2O).

Irrigation system

Watering was done following a full covering sprinkler irrigation system with 18 m x 24 m grid where PVC laterals as well as sprinklers were permanently installed over the crop cycle. Irrigation water was applied weekly following a climate-based water balance equation regarding the normal watering regime, i.e. zero water deficit, as indicated below: $I = K_c \times Pan_{Evap} - P$ Where: K_c, Pan_{Evap} and P stand for crop coefficient, class A pan evaporation and precipitation, respectively.

Sol water balance

Crop water uptake was assessed using a soil water balance model which is driven by the following simplified equation: $P + I - (ETa + D + R) = \Delta S$ over a given period Where: P (precipitation, measured), I (irrigation depth applied, as previously calculated), ETa (actual evapotranspiration, calculated), D (deep percolation, calculated by difference, the soil available moisture being determined), R (runoff which is neglected).
The soil in the experimental site was sampled over 30 cm depth at five different locations randomly chosen before setting up the trial in order to determine soil physical and chemical properties.

Field irrigation efficiency

The field irrigation efficiency, expressed in kg of cane or recoverable sucrose per cubic meter of water, is defined as the ratio of yield increase resulting from watering with respect to the rainfed treatment over the irrigation depth required. Therefore, the irrigation water use efficiency (IWUE) was assumed to be higher or at least equal to the irrigation water application efficiency (IWAE). Under good irrigation management practices, both irrigation efficiency data are supposed to be close for a given treatment:
$IWAE = (Y_i - Y_r) / (I_i - T_r)$ and $IWUE = (Y_i - Y_r) / (ETa_i - ETa_r)$ Water use efficiency (WUE) is defined as the ratio of cane stalk or recoverable sucrose yield over water uptaken by the crop (ETa): $WUE = Y_i / ETa_i$ where Y_i: yield of any irrigation treatment I_i; the semi-rainfed I_r included; Eta_i: Eta of any I_i, the semi-rainfed I_r included.

Results

Cane and sugar yields

Highly significant differences in cane as well as sugar yields were observed within irrigation treatments. Cane yields were affected by as much as 0, -18 and -69 % due to soil water deficit involving T20, T80 and T100 irrigation treatments respectively. Recoverable sugar yields were also affected by as much as -17.5, -21 and -69 % regarding T20, T80 and T100 irrigation treatments respectively. In contrast, all juice quality parameters were not significantly affected.

Cane yield response to soil water deficit

Cane yield response to irrigation deficit as well as ETa deficit has a decreasing parabolic shape, which suggests the moderately stressed T20% as the optimum level (Figure 1).

Crop growth response

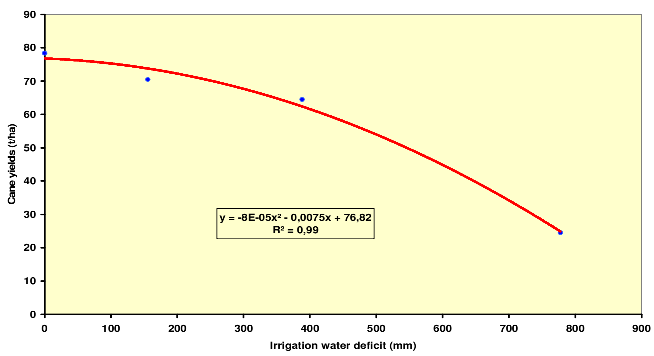
Except for the non-irrigated treatment, water deficit at the yield formation stage did not significantly affect cane stalk growth. A lower stalk growth response to irrigation was observed over the yield formation stage with an elongation rate of 0.2 – 0.4 cm/day from December 2006 to march 2007, as opposed to 0.6 cm/day recorded in mid-November 2006 (Figure 2). A much lower stalk elongation rate was observed on the non-irrigated treatment T100 with 0.1 cm/day from December 2006 to March 2007, as opposed to 0.4 cm/d measured in November 2006.

Prevailing climatic conditions

Climatic conditions over the dry season in 2006/07 cropping season were quiet favourable for cane ripening as compared to that of 2005/06. Air moisture content and average temperature magnitudes were kept respectively lower (44 %) and higher (14.9 °C) in 2006/07 as compared to 2005/6 with 50 % and 13.9 °C. That might have affected cane growth response to irrigation water at the yield formation stage under investigation.

Soil physical and chemical properties

Soil in the experimental field is moderately acid (pH=6.5) and therefore optimum for sugarcane cultivation. It is also coarse textured, with total available moisture (TAM) of 70 mm.



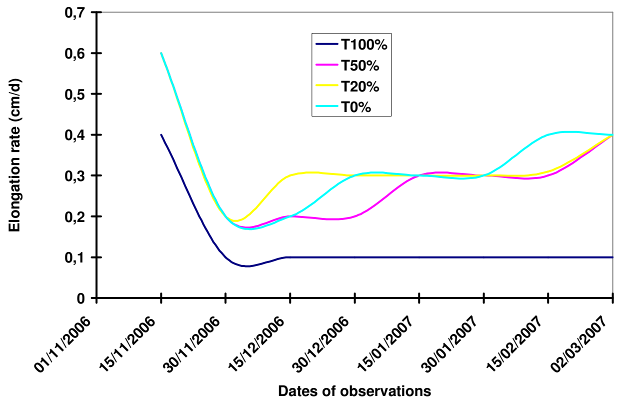


Figure 1. Cane yield response to irrigation water deficit imposed over the yield formation stage in Ferké 2 sugar mill (northern Ivory Coast).

Figure 2. Cane stalk elongation rate over the yield formation stage of a late season variety (Co 957) in Ferké 2 sugar mill (northern Ivory Coast).

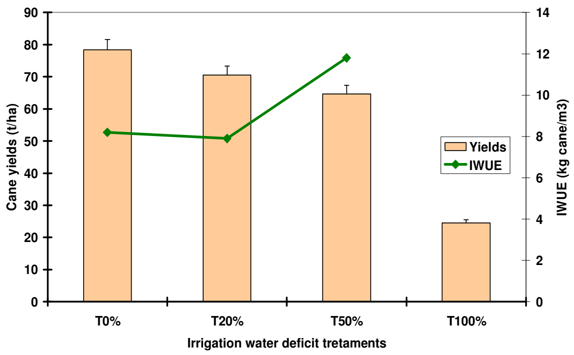


Figure 3. Cane yields and water use efficiency irrigation depending on water deficit treatments over the yield formation stage of a late season variety in Ferké 2 sugar mill (northern Ivory Coast).

The chemical status before setting up the trial was marked by a lower base saturation ratio (24 %) and a C/N ratio too high (15) which suggest a weathered soil with a slow organic matter mineralization process. Soil nitrogen and potassium contents were quiet low with 0.04 % and 0.13 meq/100 g respectively, resulting from, crop uptake but also from leaching and volatilization processes as far as nitrogen was concerned. In contrast, available phosphorous content was high (24 ppm) despite crop uptake, that element being much stable in the soil profile than nitrogen and potassium.

Field irrigation efficiency

Irrigation water use efficiency resulting from the non-stressed or fully irrigated treatment T0 (8.2 kg cane/m^3) was not significantly different from that of T20 irrigation treatment (7.9 kg canne/m^3). Therefore, additional irrigation water applied on T0 with respect to T20 in order to meet crop water requirements was not profitable (Figure 3).

Discussion

Climatic conditions and cane stalk elongation

Very low elongation rates observed over the yield formation stage despite watering of some treatments and Co 957 being a non-flowering variety, could be explained by an intensive drought enhanced by a longer lasting *harmattan* period which took place over 3.5 - 4 months instead of 1.5 – 2 as usual. As a result, a moderately performing variety like Co 957 gave high sucrose content in Ferké 2. On that site, the *harmattan* period used to be shorter (December-January) so that Co 957 could maintain a better growth rate at the yield formation stage and compensate its moderate sucrose content by higher cane yields.

Soil fertility and sugarcane yields

Lower cane yields obtained in the experiment regarding the fully irrigated treatment (78 t/ha) as well as several plantations in Ferké 2 (75 t/ha on average) might be explained partly by poor performing old varieties like Co 957, NCo 376, M 3145 and Q75 still under cultivation over about 60 % of total area, but also by soil fertility decline. That decline might have resulted from poor agricultural practices like cane burning at harvest and classical soil tillage under way more than 30 years ago. To mitigate that trend, mechanized green cane harvesting, cane trash blanketing, minimum soil tillage as well as sugarcane-based legume crop rotation system are being promoted on Ferké 2 plantations since 2006. Such a new farming system in sugarcane is of concern in most large sugarcane producing countries (Robertson, Thorburn, 2007a, 2007b; Pankhurst, Magarey *et al*, 2003; Doerr, Cerda, 2005).

Cane yields and quality in commercial fields

Cane yield reduction with respect to yield predictions on late season varieties was high (10-20 %) due to exceptional climatic conditions over the yield formation stage in Ferké 2. In contrast, cane juice quality was quiet high with 16-17 % of sucrose content and 95-96 % of purity obtained in the field. This has mitigated sugar production loss as compared to initial estimates. Some extra sugar production (10-15 %) was obtained compared to estimates, as better cane yields and quality were achieved. Eventually, initial production estimates were met by 99 % on commercial plantations and by 112 % on village plantations.

Soil water deficit at yield formation of late season cane varieties. The study showed the relevance of 20 % water deficit imposed at the yield formation stage of Co957 as a non-flowering late-season cane variety in order to increase the field irrigation efficiency. This finding was not in line of results from similar study carried out on a neighbouring experimental station (Péné, Chopart *et al*., 2007) which suggested a normal watering regime at yield formation on the same variety because of its growth potential at that growth stage. This suggests the yield response of that variety to water deficit be dependent on the intensity as well as the duration of the *harmattan* period prevailing over the yield formation stage under late irrigation season. As far as some late cane varieties prone to flowering like M 3145 and R 570 were concerned, previous studies reported a limited yield response to irrigation at that growth stage and the profitability of managing a moderate water deficit by 20 to 30 %, in order to increase field irrigation efficiency and achieve some substantial water savings (Péné, Assa *et al*., 2001). In general, the study shows that cane yield response to water deficit is depending on variety, crop growth stage, pedo-climatic conditions as well as the watering strategy adopted (Gaudin, Brouwers *et al*., 1999; Martiné, 1999).

Conclusion

We found that 20 % water deficit was the optimum level which gave a field irrigation efficiency of 7.9 kg cane/m^3 of water, i.e., 0.98 kg sugar/m^3 of water. Also, lower cane stalk elongation rates as well as cane yields were obtained on a non-flowering late season variety like Co 957 as a result of an intensive and long lasting dry season observed over the yield formation stage. On the other hand, with drought enhanced by the *harmattan* period, a better cane juice quality was measured on Co 957 which used to be a moderately performing variety in Ferké 2 sugar mill. This finding is a sound contribution for a better water management strategy over the yield formation stage of late season cane varieties under cultivation in northern Ivory Coast.

References

Frère M, Popov GF (1987) Suivi agrométéorologique des cultures et prévision des rendements. *Etude FAO Production végétale et protection des plantes* 73.

Gaudin R, Brouwers M, Chopard JL (1999) L'eau utile et les caractéristiques hydrodynamiques des sols sous culture de canne à sucre. *Agriculture et Développement* **24**, 30-38.

Martiné JF (1999) Croissance de la canne et stress hydrique: Les apports d'un modèle plante. *Agriculture et développement* **24**, 21-28.

Ooerr SH, Cerda SH (2005) Fire effects on soil system functioning: new insights and futur challenges. *Inter. J. of Wildl. Fire* **14**(4), 339-342.

Pankhurst CE, Magarey RC, Stirling GR, Blair BJL, Bell MJ, Garside AL (2003) Management practices to improve soil health and reduce the effects of detrimental soil biota associated with yield decline of sugarcane in Queensland, Australia. *Soil & Til. Res*. **72**(2), 125-137.

Péné CB (1999) Diagnostic hydrique en culture cannière et gestion du risque climatique : cas de Ferké 2 et de Zuénoula, en Côte d'Ivoire. *Agricult. & Dév*. (n spécial sur la canne à sucre et l'eau) **24**, 74-80.

Péné CB, Assa DA, Déa BG (2001) Interactions eau d'irrigation-variétés de canne à sucre en conditions de rationnement hydrique. *Cahiers Agricultures* **10**, 243-53

Péné CB, Chopard JL, Assa DA (1997) Gestion de l'irrigation à la parcelle en culture de canne à sucre (*Saccharum officinarum L.*) sous climat tropical humide, à travers le cas des régions Nord et centre de la Côte d'Ivoire. *Sécheresse* **8**(2), 87-98.

Péné CB, et Kéhé M (2005) Performance de trois variétés de canne à sucre soumises au rationnement hydrique en prématuration au Nord de la Côte d'Ivoire. *Agron. Afr.* **17**(1), 7-18.

Péné CB, Tuo K (1996) Utilisation du diagnostic hydrique pour le pilotage optimal de l'irrigation de la canne à sucre en Côte d'Ivoire. *Sécheresse* **7**(4), 299-306

Robertson FA, Thorburn PJ (2007a) Decomposition of sugarcane harvest residue in different climatic zones. *Austr. J. Soil Res*. **45**(1), 1-11.

Robertson FA, Thorburn PJ (2007b) Management of sugarcane harvest residues: Consequences for soil carbon and nitrogen. *Aust. J. Soil Res*. **45**(1), 13-23.