Improving yield and water use efficiency of sugarcane under drip irrigation in the Gharb region of Morocco

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Abstract

One of the most limiting factors for agricultural development in Morocco is water scarcity linked to climate change. Since 2008, an important program promoting drip irrigation was undertaken by the state to achieve water saving and productivity. An experiment on sugarcane was conducted in the Gharb region under Mediterranean climate with a silty clay soil during two cropping seasons. The objectives were to assess the sugarcane water requirements, optimize WUE and test the crop response to variable irrigation water supplies under drip irrigation. The experiment was conducted using ''CP70-321'' sugarcane cultivar in an experimental station using a randomized block design with four replications and five water regimes. The results showed a highly significant effect of the water regime on sugar and stems yields and also on height of stems. Water requirements for sugarcane were estimated at 7500 $m^3.ha^{-1}$, but 5000 $m^3.ha^{-1}$ equivalent to 67%ETc, was sufficient to optimize WUE (132 to 157 kg of stems $ha^{-1}.mm^{-1}$ and 22.2 to 24.2 kg of sugar $ha^{-1}.mm^{-1}$. This means that drip irrigation on sugarcane could potentially i) save about 50% of the irrigation volume, comparatively to sprinkler irrigation, ii) almost double the stem yields and iii) increase the sugar yields from 8 to 23 tons/ha.

Keywords: Sugarcane, Water use efficiency (WUE), Gharb, Morocco

Résumé

Au Maroc, la rareté de l'eau liée au changement climatique, constitue le facteur limitant principal du développement agricole. Depuis 2008, un programme de reconversion à l'irrigation localisée a été entrepris par l'état pour mieux valoriser et économiser l'eau d'irrigation. Un essai a été conduit durant deux années sur la canne à sucre dans le Gharb sous un climat méditerranéen avec un sol argilo-limoneux. Les objectifs étaient de déterminer les besoins en eau de la culture, d'optimiser l'EUE et d'évaluer la réponse de la culture à différents apports d'eau en mode d'irrigation localisée. L'expérimentation a été conduite en utilisant la variété "CP70-321" avec un dispositif en blocs aléatoires randomisés, quatre répétitions et cinq régimes hydriques. Les résultats ont montré un effet hautement significatif du régime hydrique sur les rendements en tiges et en sucre et sur la hauteur de végétation. Les besoins en eau d'irrigation sont de 7500 $m^3.ha^{-1}$, mais 5000 $m^3.ha^{-1}$ équivalent à 67%ETM serait un volume suffisant pour optimiser l'EUE (132 à 157 kg de tiges $ha^{-1}.mm^{-1}$ et 22,2 à 24,2 kg de sucre $ha^{-1}.mm^{-1}$). L'irrigation localisée pourrait donc conduire à: i) économiser environ 50 % d'eau apporté comparativement à l'irrigation par aspersion, ii) presque doubler le rendement en tiges et iii) améliorer le rendement en sucre d'environ 8 à 23 tonnes/ha.

Mots clés: Canne à sucre, Efficience d'utilisation de l'eau, Gharb, Maroc

INTRODUCTION

Moroccan agriculture is undergoing social, economic and environmental changes. One of the most limiting factors for agricultural development is water scarcity linked to climate change which has negative implications on the future sustainability of current cropping systems. This is why since 2008, an important program of reconversion to drip irrigation was undertaken by the state in order to achieve more water saving and water productivity. Sugarcane is one of the important crops in the Gharb irrigation scheme. Sugarcane (*Saccharum officinarum L.*) was introduced in the Gharb region in 1972. Actually, the cropped area is about 20.000 ha nationwide of which 15.000 ha are located in the Gharb. This crop contributes to about one-third of the Moroccan sugar production. Irrigation is necessary due to the crop's tropical origin and its growing period which, in Morocco, coincides with the hot and dry summer season. Consequently, more than 70% of its overall water consumption, which actually ranges, under sprinkler irrigation, between 11.000 m^3 and 15.000 $m^3.ha^{-1}.year^{-1}$, are supplied between April and October (Aabad, 2002; Si Hammou, 2004). One of the important questions is how to reduce its water consumption and increase the yield. In the Gharb area, sugarcane ranks among the crops with very limited irrigation water productivity when compared to vegetables or fruit trees (Si Hammou, 2004). Irrigation water supply efficiency (stem yield divided by the total amount of water supplied to the crop during the growing

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cycle) of sugarcane is about 0.7 to 0.8 kg.m^{-3}, which is less than the result obtained for sugar beet (1.3 kg of sugar.m^{-3}; Si Hammou, 2004; Aabad and *al*., 2008). In the Gharb region, the average yield of millable stems is 70 t.ha^{-1}.year^{-1} with a sucrose content of 11,5% (ORMVAG, 2007). The regional potential stem yield under sprinkler irrigation ranged from 100 to 120 t.ha^{-1}.year^{-1} (Ziyad, 1990; Aabad, 2002).

The objectives of the present study were to assess the sugarcane water requirements, optimize WUE and test the crop response to variable irrigation water supplies under drip irrigation. This last term expresses the yield divided by the actual evapotranspiration of the crop (Cooper et *al*., 1987) and was used in order to take into account the soil surface evaporation and the crop transpiration. Those experiments are the first ones conducted with drip irrigation in Morocco on sugarcane. The results of these experiments will provide references in terms of water saving related to water productivity specifically on clay soils presenting shrinking and swelling phenomenon related to desiccation and humectation of the soil. Another important consideration is that Morocco is highly concerned by adaptations to climate change. The preliminary trend analysis of available rainfall data suggests that the climate change impacts will decrease the precipitation on the Atlas Mountains of Morocco, which are the main source of water supplies in western Moroccan irrigated perimeters (Chaponniere and Smakhtin, 2006; Bouabid and Chafai Elalaoui. 2010; Driouech et *al*. 2010). On the other hand, irrigation systems efficiencies are about 0.5, 0.7 and 0.95 respectively for surface, sprinkler and drip irrigation (Bouaziz et Belabbas, 2002). In this perspective, the Moroccan strategy for irrigation was based from 2007 onwards to converting about 550,000 hectares from surface to drip irrigation through a vast subsidy program. Those first experiments on drip irrigation are highly important for agronomists and irrigation scientists to establish references on water saving and were used also to convince farmers and policy makers on the utility of the conversion of surface and sprinkler irrigation systems to drip irrigation.

MATERIALS AND METHODS

The Gharb specific context

The Gharb Region was subdivided into three agro ecological zones, which were labeled uniform territorial areas (UTA). The first UTA is the coastal zone characterized by sandy soils in their majority, private water pumping through wells and favorable climatic conditions for the sector of fruits and vegetables. The second UTA is the central plain where the majority of soil types are heavy silty clay soils and deficient in drainage. The experimental site is located in this unit. Table 1 shows that the clay percentage is more than 50% and the silt is about 45%. The organic matter decreases with the soil depth and the pH is in the basic range. It also shows that potassium is in a high range of availability for normal plant growth and development (K fertilizer is not necessary). The soil bulk density is more than 1.4 T/m^3 but allowing sufficient soil aeration for root growth and germination with a total porosity more than 40%.

A large part of this UTA is included in the Gharb large-scale irrigation scheme (surface and sprinkler irrigation). It offers important potentialities for citrus fruit crops, cereals, grain legumes, forages and sugar crops.

The third UTA is a rain fed zone (bour) with plains and small piedmonts for the cultivation of cereals and olive trees.

Three types of cropping systems are practiced in the Gharb: **i)** the vegetable intensive farming systems; **ii)** the field crop systems: wheat, grain legumes, sunflower, etc and **iii)** the tree crop systems: citrus fruits, olive tree, banana, avocado tree, etc.

The region has a semi-arid climate with an average total rainfall of 538 mm per year mainly between October and April (Figure 1). The calculated Pan evaporation and the sugarcane crop evapotranspiration are respectively 1625 and 1044 mm/year. The climatic water deficit occurs mainly between April and October. The temperatures are generally clement (Minimum: 6°C in December and Maximum 30°C in July) and sufficient water resources are available for irrigation annually (Taky, 1996). Indeed, this zone counts 5 billions of m^3 in surface water (27 % of the water volume on a national scale) and 960 billions m^3 in underground water for a total potentially irrigated area of 177 800 ha. However, there is a water deficit in summer. The average farm size is about 4,3 ha (ORMVAG, 2007). The total arable land of the region is 518 300 ha and represents 64 % of the total surface of the Region and 6 % of the national arable land. 87 % of the farms have less

Table 1: Soil characteristics of the experimental site

Layer (cm)	Soil size of particles (%)					Soil limestone (%)		Organic Matter (%)		Assim. P_2O_5	Exchang. K_2O	pH water	NaCl	Bulk density (t/m^3)
	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total	Active	OM	C	(‰)	(‰)	_	(1/5)	-
0-30	50.7	45.2	3.5	0.3	0.3	17.9	13.0	2.45	1.14	0.019	0.282	8.00	0.19	1.45
30-60	54.8	44.4	0.2	0.3	0.3	17.9	11.0	2.41	1.04	0.002	0.235	7.95	0.24	1.58
60-90	50.7	46.4	2.4	0.3	0.2	20.8	12.5	1.07	0.62	0.001	0.170	8.02	0.28	1.58
90-120	43.1	51.4	5.2	0.3	0.0	23.7	12.5	0.67	0.54	0.001	0.152	8.18	0.35	1.52

than 5 ha and occupy 32 % of the total arable land (SAU) and 4.45 % have more than 20 ha and represent 30 % of the arable land (ORMVAG, 2007).

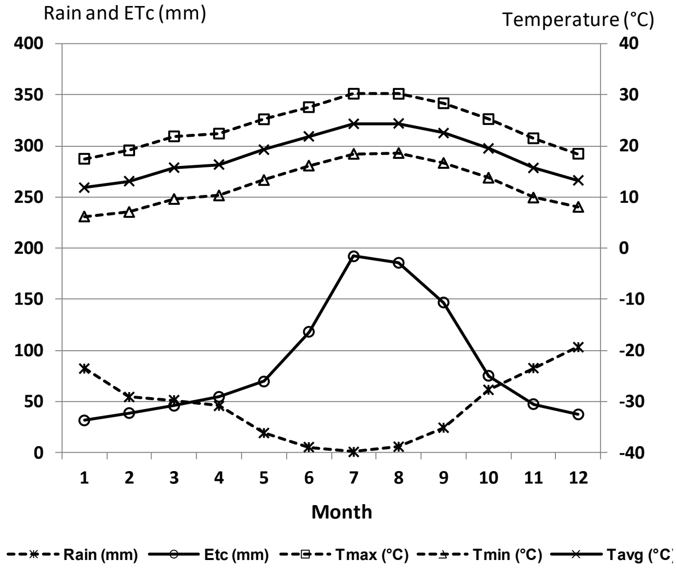

Figure 1: Rainfall, crop evapotranspiration (ETc) and Temperature regimes

The Experimental design

The experiments were conducted in the Research Unit of the Technical Center for Sugar Crops (CTCS) in the Gharb, which is about 90 km north of Rabat and close to the Atlantic coastal area. Under this Mediterranean climate, the Bac class A evaporation ranged from about 1.8 mm/day in January to about 7.5 mm/day in July. The sugarcane growth occurs between April and October because temperatures are higher than 15°C. During its growing season, sugarcane must be irrigated because of insufficient rain. The trial was conducted on a one-hectare plot using cultivar `CP70-321'. Water was supplied on the row and sugarcane inter rows was 1,50 m. Drip irrigation was set up using 30 cm dripper spacing on the same row and a nominal flow of 7,1 $L.h^{-1}.m^{-1}$ with a pressure head of 0,08 MPa. The control treatment received an amount of water equivalent to 100%ETc. In order to have a wide range of water stress and test the crop response to water regimes, different percentages of water supplies reduction were adopted beside of the control (100 ETc): 2/3 or 67% ETc, ½ or 50% ETc, 1/3 or 33% ETc and 1/6 or 17% ETc. The amounts of water were measured via flow meters placed at the head of each elementary plot. A randomized blocks design with four replications and five irrigation regimes was then adopted. The five irrigation regimes were defined as follows: 100, 67, 50, 33 and 17 % ETc. In order to supply the crop with significant amounts of water and reduce the measurements errors, the irrigation frequency was once a week for 33% and 17% ETc treatments (small amount of water) and twice a week for the other treatments (100%, 67% and 50% ETc). In the beginning of the growing season, the same amount of water was applied to all the treatments in order to reach the soil field capacity and ensure a homogeneous germination and emergence of the crop, after that stage the reductions or water regimes were applied.

The experimental unit corresponded to 4 lines of sugarcane of 45 m in length with inter-row spacing of 1,50 m which is equivalent to 270 m². Measurements were carried out during the cropping seasons of 2005/2006 and 2006/2007 corresponding to first and second sugarcane ratoons (R1 and R2). The first one (R1) covered the period between February 2005 and April 2006 (15 months) with a cumulative rain of 564 mm whereas the second one (R2) was realized between June 2006 and June 2007 (12 months) with a total rain of only 321 mm.

Estimation of irrigation water requirements

The following formula was used to estimate irrigation water requirement of the crop (ETc according to Doorenbos and Kassem, 1980):

$$ET_c = K_c \times ET_0 \text{ (FAO, 1998)} \qquad (1)$$

A class A pan evaporation (E_{pan}), set up 'in situ' in the CTCS weather recording station, was used to estimate the reference evapotranspiration (ET_0). ET_0 is provided by the daily pan evaporation product (E_{pan}, mm/day) as well as by pan coefficient (Kp):

$$ET_0 = K_p \times E_{pan} \qquad (2)$$

ETc calculation is described by the following equation:

$$ET_c = K_c \times (K_p \times E_{pan}) \qquad (3)$$

Previous test trials conducted at CTCS center between 1985 and 1990 allowed us to determine the values of K_C and K_p coefficients for the various stages of the crop cycle (El Messaoudi, 1990). According to the studies undertaken by the last author, these coefficients are as follows (Table 2):

Table 2. Values of the product Kc x Kp during the sugarcane growing season

Age of crop (month)	0 – 2.5	2.5 – 3.5	3.5 – 6.5	6.5 - 12
Kc	0.40	0.85	1.25	0.75
K_C x K_p	0.40	0.60	0.85	0.60

Source: El Messaoudi, 1990

Irrigation water requirements (IWR, mm) needed to compensate water stress (WS, mm) was computed using the following formula:

$$IWR = WS/0.95 = (ETc - ER)/0.95 \qquad (4)$$

The efficient rain (ER) was estimated according to the literature to stand at 80% of rainfall, including water losses due to shade effect, evaporation, run-off and percolation in the soil cracks (Benhaida, 2001; Taky, 1996). Efficiency of drip irrigation system was considered equal to 95%.

Estimation of stem and sugar yields

Studies undertaken by Gay *et al.,* (1997) on biomass spatial variability during period of harvest showed that variation coefficients became stable when sample plots becomes equal or greater than a sugarcane line of 3 meters of length. Consequently, estimates of stem and sugar yields as well as analysis of technological quality were carried out using a set of 3 linear meters test plots randomly selected inside the experimental units.

Observations relating to height, stands and number of leaf blades per stem

40 stems per test plot were chosen randomly toward the end of each growth cycle. Heights were measured and leaf blades counted right from the stem base to the Terminal Visible Dewlap ('TVD', Védié, 1993). As for the stands, stem count is performed right after harvest on 3 randomly selected linear meters.

Computation of Water Use Efficiency (WUE)

Actual evapotranspiration was computed as shown in the following equation, by summing irrigation water (IW), effective rainfall and the variation of soil water storage (VSWS) during the crop growing season:

$$ETa= IW+ER+VSWS \qquad (5)$$

The considered soil depth for water balance was 60 cm were a maximum of roots was localized. According to our observations, 90% of the roots were above a depth of 70 cm. This confirms the results reported by Blackburn (1984) and Smith et *al.,* (2005) where about approximately 50% of root biomass occurs in the top 20 cm of soil and 85% in the top 60 cm. Percolation losses and runoff can be neglected because of the drip irrigation practice. During the first stage of the irrigation, the soil is dry and some water runoff could go directly into the soil cracks. Irrigation water (IW) supplied was measured for each treatment and variation of soil water storage (VSWS) can be calculated using soil moisture and bulk density for each soil layer. The soil moisture was measured using the gravimetric method each month on four layers (0-30, 30-60, 60-90 and 90-120 cm) and the bulk density twice a year.

Water Use Efficiency (WUE) was calculated as follows:

$$WUE = Y / ETa \qquad (6)$$

Where:

WUE: water use efficiency (kg/m^3)
Y: stems or sugar yield (kg.ha^{-1})
ETa: Actual evapotranspiration (m^3/ha)

Statistical analysis

The experimental results were analyzed and compared under randomized bloc design. The least significant difference (LSD) between the irrigation treatments was computed using the following formula reported by Cochran and Cox (1957):

$$LSD = (\sqrt{2VEr^{-1}}) \times t_{5\%} \qquad (7)$$

Where:

VE: = variance error

r: number of replications

$t_{5\%}$: table value of t at 5% level of significance at error degree of freedom

RESULTS AND DISCUSSIONS

Water supplies per treatments

Prior to individualizing the water application of the various treatments, the soil water reserve at the beginning of each cycle, was set equal to field capacity. To reach this goal, the total added amounts in May and June were 1650 m^3/ha and 1200 m^3/ha during the first and second growing season of the experiment corresponding to R1 and R2 crop ratoons. The recorded precipitations were 564 mm for R1 (February 2005 – April 2006) and 321 mm for R2 (June 2006–June 2007). The total supplies for the control water regime (100% ETc) were 7109 and 6454 m^3.ha^{-1} respectively for the two growing

Table 3: Water supplies during the first (R1, 2005/2006) and second ratoon (R2, 2006/2007)

Months	Water supplies (m^3.ha^{-1}) / Water Regime (% ETc) and years of Inflows									
	100%		67%		50%		33%		17%	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May and June (*)	1650	1200	1650	1200	1650	1200	1650	1200	1650	1200
July	1948	1005	1305	674	974	503	643	332	331	171
August	1577	1499	1057	1005	789	750	520	495	268	255
September	988	1902	662	1275	494	951	326	628	168	323
October	734	725	492	485	367	362	242	239	125	123
November	212	0	142	0	106	0	70	0	36	0
May (2007)	0	52	0	35	0	26	0	17	0	9
June (2007)	0	70	0	47	0	35	0	23	0	12
TOTAL	7109	6453	5308	4721	4380	3827	3451	2934	2578	2093

(*): 100%ETc were generalized for all treatments seasons of 2005/2006 and 2006/2007. Table 3 displays water supplies per month as well as the total amount per year for each treatment during R1 and R2 growing cycle. The total water supplies obtained by drip irrigation system showed a water saving of about 50% when compared with sprinkler irrigation where the total water amount ranged from 11 to 15000 $m^3.ha^{-1}.year^{-1}$ at the farm level in the Gharb area (Ziyad, 1990; Aabad, 2002; Si Hammou, 2004). This could allow expansion of the cropped sugarcane area or a reallocation of water surplus to irrigate other crops, such as sugar beet, vegetables, tree cropping, forage or cereals.

Stems and sugar yields

For R1 and R2 ratoons, the stem and sugar yields increased with irrigation water ratios (Figure 2). The highest yields were obtained when the water requirements of the crop were fully satisfied (100%ETc). For the two growing seasons, the difference was not significant between the 100 and 67%ETc treatments. This was the case also for 33 and 17% treatments. Ranking of averages stem yield showed three groups of treatments with significant differences: i) 100% and 67%ETc, ii) 33 and 17 %ETc and iii) 50%ETc, which was intermediary. For the first ratoon, water applications of 100%, 67% and 50%ETc yielded respectively 142, 134 and 114 $t.ha^{-1}$ *vs* 98 and 89 $t.ha^{-1}$ obtained respectively for 33% and 17%ETc water regimes (Figure 2). For the second ratoon, the yields were 133, 126 and 107 $t.ha^{-1}$ *vs* 91 and 81 $t.ha^{-1}$ respectively for different water regimes. These yields are relatively high when compared to the average yield of 70 $t.ha^{-1}$ obtained in large-scale agriculture in the Gharb region (ORMVAG, 2007). This clearly shows the existence of a considerable gap between the actual and potential yields achievable through the use of drip irrigation system in the Gharb region.

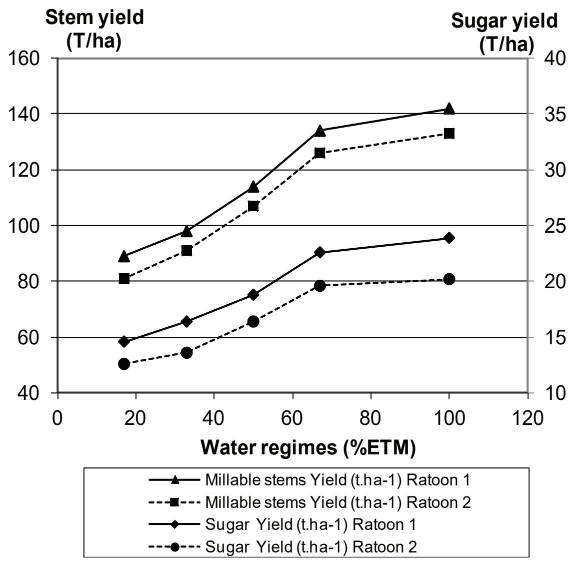

Figure 2: Sugar and stem yields (T/ha) for R1 and R2

The same tendencies, shown on stem yields were observed for sugar yields. The highest yields were obtained for 100% and 67%ETc water regimes, respectively, 23.9 and 22.6 $t.ha^{-1}$ for R1 and 20.2 and 19.6 $t.ha^{-1}$ for R2 (Figure 2). The differences between the two treatments were not significant. These yields were quite high when compared to the average yield obtained in the sprinkler irrigation scheme (6 and 8 t sucrose. ha^{-1}; Aabad, 2002). Wiedenfeld (1995) stated that in an experiment involving three production cycles the highest levels of irrigation always produced the best results in millable terms and sugar yields.

For the two ratoons (R1 et R2), the noticed differences in sugar yields could be related to the differences in the length and position of the ratoon cycles, cumulative rainfall and mainly amounts of irrigation water supplies (Figure 2). The yield increases tendencies were the same for the two growing seasons. A highly significant correlation (R^2=0.94) was equally noticed between sugar yield and millable stems yield, which confirms the fact that these two quantities actually display the same evolutionary trends.

Effect of irrigation water regimes on growth parameters

Elongation of the stems

During the two growing seasons corresponding to R1 and R2 ratoons, the water stress resulted in a significant effect on height of stems (Figure 3). The stem height increases with irrigation water supplies.

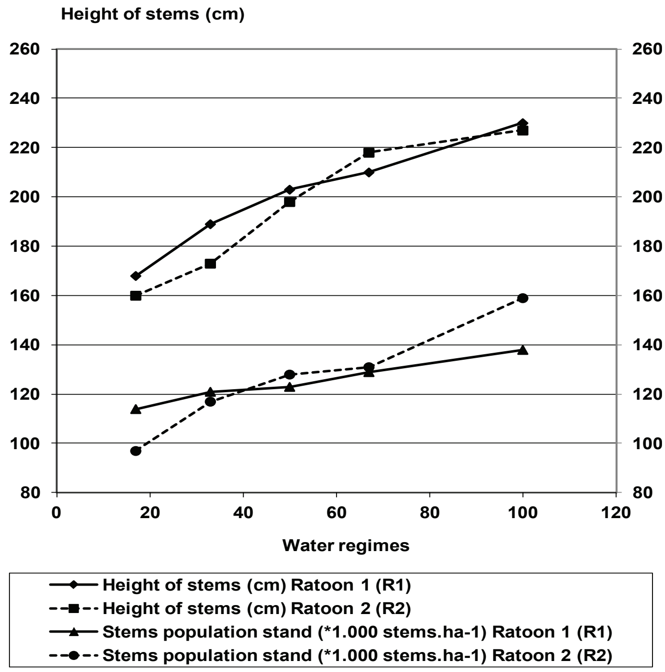

Figure 3: Height of stems (cm) and stems population stand ($stems.ha^{-1}$)

Average elongation rates achieved during he period of irrigation occurring between July and November were 1.30; 1.14; 1.05; 0.94 and 0.78 cm per day for 100; 67; 50; 33; and 17% ETc treatments respectively. These differences between growth rates of stems had proportionate consequences on final stem yields at harvest (Figure 2). Our results confirm those obtained by previous studies, highlighting the importance of the relationship between sugarcane growth rates and water availability in the soil (Inman-Bamber and Smith, 2005; Péné and Edi, 1997). During the irrigation period of sugarcane in summer (July-October), which usually coincides with the active growth phase or "boom stage", the water requirements of the crop under our trial conditions at full irrigation regime (100%ETc) have been estimated to stand at about 4.5 mm.d^{-1} in 2005 on average, with a minimum of 4.1 mm.d^{-1} in 2005 and a maximum of 4.8 mm.d^{-1} in 2006.

Stem population

For the first growing season (R1), despite a downward trend in connection with the water deficit (Figure 3), the overall number of stems.m^{-2} did not display any significant difference between the treatments. For R2, however, a significant effect of the water regimes on population stand establishment was noticed. This effect was quite favorable for irrigation water regimes exceeding 50% ETc and negative for those treatments where sugarcane was kept under a water stress (33 and 17%ETc) for R1 and R2. Our hypothesis for the difference in term of number of stems.m^{-2} was the position and duration of the tillering period during the growing season. We assume that in the first growing season (R1) which covered the period between February 2005 and April 2006 (15 months), the tillering phase occurred during the first three month in less favorable conditions (temperatures cooler, lower solar radiation,...) with more cumulative rain (564 mm) so the water stress factor, despite the tendency, was not significant. In the opposite, for R2 growing season (June 2006 and June 2007), sugar cane crop tillering period occurred under higher temperature and solar radiation, with a total rain of only 321 mm, so the effect of the water stress was significant. It seems, therefore, that during the first stages of growth when the establishment process of the vegetation stand is intensive, a water requirement rate of about 50%ETc can be considered a minimum irrigation threshold for sugarcane in the Gharb. The difference in terms of population stand (stem.ha^{-1}) between R1 and R2 ratoons can be related to the crop cycle positions in the year and particularly the start of the cycle which was in February for R1 and June for R2.

Technological quality

The analyses were carried out using three basic evaluation criteria related to sugarcane technological quality (Table 4): amount of sucrose or sugar content (% of sucrose), purity of juice (% of juice) and fiber content (fiber in % of stem).

Sucrose content (%)

For the two sugarcane ratoons, all treatments have given sucrose contents varying between 15 and 17% (Table 4). Those contents are relatively high when compared to the average of about 11,5% obtained under the sprinkler irrigation system and farmers' practices in the Gharb area (Benhaida, 2001 and SURAC, 2002) for the same variety. Differences induced by the water regimes were not significant. This confirms the results of the different experiments carried out in the Gharb by Aabad (2002) and Ziyad (1990) who also did not show any significant effect of irrigation regime on sucrose content of sugarcane. According to Martiné (1999), the severest water deficit did not generally lead to a reduction in the production of sugar by the plant. This is due to the fact that in the water stressed conditions, the carbohydrates assimilated resulting from the photosynthesis process contribute preferentially to the activity of sucrose production and not to growth and development of stems, which is reduced.

Purity of juice (%)

For the two ratoons, purity rates obtained for the aggregate of treatments vary between 87 and 90 % (Table 4). Under our conditions, the volume of irrigation water has no significant influence on juice purity. The same findings were reported by Singh *et al.,* (2007) in India, Allali and Enahari (2001) in Morocco and Péné and Edi (1995) in Ivory Coast.

Fiber content (%)

There were no significant differences between the water regimes in terms of fiber contents (Table 4). Sugarcane fiber contents would therefore be a feature attributable more to the genotype than to factors other than those linked to irrigation. Similar findings were reported in the literature by Aabad (2002) and by Allali and Enahari (2001) in Morocco. Under the tropical conditions in Reunion Island, low water deficits (water storage index ranging between 0.7 and 0.8) did not significantly affect neither growth of sugarcane organs nor impact on fiber or biomass accumulation (Martiné, 1999).

Table 4: Technological quality of millable stems

Water Regimes	Sucrose content (%)		Purity (%)		Fiber (%)	
	Ratoon 1 (R1)	Ratoon 2 (R2)	Ratoon 1 (R1)	Ratoon 2 (R2)	Ratoon 1 (R1)	Ratoon 2 (R2)
100%ETM	16.8 a	15.2 a	89.5 a	88.3 a	12.1 a	14.9 a
67%ETM	16.8 a	15.6 a	90.2 a	87.6 a	12.2 a	14.5 a
50%ETM	16.4 a	15.3 a	88.8 a	88.9 a	12.1 a	14.3 a
33%ETM	16.7 a	15.9 a	90.1 a	87.4 a	12.3 a	14.8 a
17%ETM	16.5 a	15.5 a	89.6 a	86.9 a	12.4 a	14.0 a
PPDS	0.60	0.79	1.99	1.99	0.99	2.41
CV %	2.36	3.38	1.44	1.48	5.26	10.79

Data within the same column followed by the same letter are not significantly different.
R1 and R2: First and second Ratoons

Relationship between stem yield and plant canopy state variables

For the purpose of quantifying the relationship between stems yield, plant canopy state variables, population stand as well as the number of leaf blades produced by each stem, a statistical analysis was carried out to clarify the relationships between these variables and the yields for the two growing seasons. The results showed a significant correlation between yield and height of stems. However, the link between yield and population stand was less clear. As we saw before, for the population stand defined as the number of millable stems per hectare, it appears clearly that the yield establishment is more related to height and weight of the stems for the first growing season (R1) and more to the population stand for the second ratoon (R2). The correlation was lower between the yield and the total number of blades produced by stem (Table 5). This confirm the fact that the number of leaves is more related to organogenesis which occurs before the period of water stress.

The results reported in this part confirmed those reported in earlier studies (Aabad, 2002 and 2008) and clearly highlight the close relationship between elongation of stems and yield of millable sugarcane. For a given cultivar, elongation of stems can be considered as the main component in sugarcane yield establishment.

Water use efficiency (WUE)

WUE (kg of stem/ha/mm or kg of sugar/ha/mm) was calculated from the water balance components such as the total irrigation water, the effective rainfall (80% of total rainfall) and the contribution of the soil profile during the growing season as explained before. In our context, the total calculated effective rain were 451 mm for the first growing season R1 (2005/2006) and for ratoon 2 257 mm for R2 (2006/2007).

The results showed that the optimal WUE for sugar and stems were obtained by 67% ETc treatment (Figure 4). For the two consecutive years of the experiment maximum WUE were about 132.3 and 156.7 kg of stems/ha/mm and 22.2 and 24.4 kg of sugar/ha/mm respectively. Those differences between the two years were related mainly to the growth duration: 15 months for R1 and 12 months for R2. In previous experiments and surveys undertaken in the Gharb area with sprinkler and surface irrigation, Aabad (2002) and Si Hammou (2004) showed that marginal water use of the irrigation water (yield divided by water supply) varied from 60 to 70 kg of stems/ha/mm and 7 to 10 kg of sugar/ha/mm. In these conditions a large part of water was lost in deep percolation. In India, and on a silty clay loam soil, Sing et al. (2007) reported that the average WUE for ratoon cane was 63 kg.ha^{-1}.mm^{-1}. The authors specified that water losses by deep percolation of water were estimated to 25 – 30% for the first year and 7 to 13% for the second year. In their experiments the yields ranged from 60 to 74 t.ha^{-1} and the water amounts overreached 10,000 m^3/ha. On the other hand, another experiment, conducted in India by Thiyagarajan et *al.,* (2011), revealed that, drip irrigation at 60% PE (Pan evaporation) recorded a significantly higher sugarcane yield of 164.8 t ha^{-1} with an enhanced water use efficiency of 166.1 kg of stems/ha/mm. These results confirm ours and showed the importance of drip irrigation particularly in reducing water losses by water percolation and increasing stem and sugar yields.

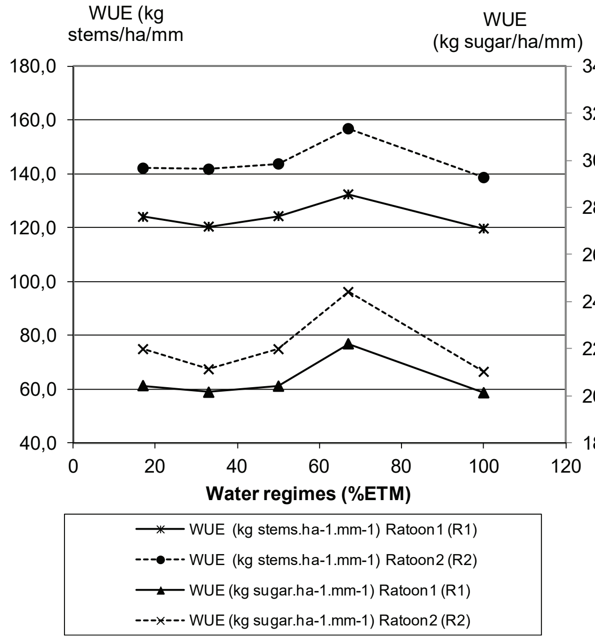

Figure 4: Water use efficiency for stem and sugar production (R1 and R2)

CONCLUSION

In this article, emphasis has been put on the experimental results of drip irrigation for sugar cane in the Gharb area in order to improve crop water use efficiency comparatively to the actual system where sprinkler irrigation is commonly used. Those experiments served also via field days to

Table 5: Correlations between millable stems yield and state variables of plant canopy.

Statistical Criteria	Correlations between yield of millable stems and		
	Height of stems	Stems Population stand	Number of leaf blades/stem
Equation of regression line	Y=0.7X-29.8	Y=0.0005X+45.6	Y=1.9X+67.5
Coefficient of determination	R^2=0.68	R^2=0.32	R^2=0.10
Residual standard duration	rmse=12.5	rmse=18.3	rmse=21.1
Coefficient of variation (%)	CV=11,2	CV=16.4	CV=18.9

convince farmers and decision makers for the introduction and adoption of this technology at the farm level. This region is known by its specific context characterized by a Mediterranean climate (dry and hot in the summer and rainy with low temperatures in the winter) and very heavy clay soil with shrinking and swelling phenomenon.

The results showed that the drip irrigation system permitted to reduce water supplies comparatively with sprinkler irrigation used in the Gharb area. Recently a survey realized by Si Hammou (2004) showed that yield reached an average of 68 t/ha for a water consumption of about 11 330 m^3/year or sugar cane cycle. Our experiments have shown that an average water supply of about 5.000 $m^3.ha^{-1}$ corresponding approximately to 67 %ETc is sufficient for enhancing substantially stems and sugar yields (134 and 126 t of $stems.ha^{-1}$ and 23 and 20 t of $sugar.ha^{-1}$ for the two ratoons 2005/2006 and 2006/2007, respectively). The highest yields were obtained with 100 and 67 %ETc. But these two treatments were not significantly different.

Consequently, WUE was improved both for stems or for sugar production. A possible water saving of about 50% was obtained by supplying the crop with 67% of its water requirements (ETc). Those results will probably push the agency in charge of water management (ORMVAG) to extend the sugar cane area devoted to drip irrigation and to reallocate the water saved to irrigate other crops, such as sugar beet, vegetables, tree crops, forage or cereals.

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