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Coil irrigation in sugar cane (*Saccharum officinarum*)

Jesús A. Sánchez Gutiérrez[1], Yoslen Fernández Gálvez[2], Mayra Martínez Pírez[3], Camilo Bonet Pérez[4], Manuel A. Hernández Victoria[5] & Arlandy Noy Perera[6].

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ABSTRACT

This study was made at the Basic Seed Bank of the Local Sugar Cane Research Station for the Mideastern Cuba, based in Camaguey, on brown carbonate soil, between 2013 and 12014. Coil irrigation was applied to meet the water requirements for the crop, according to the edafoclimatic conditions and the different phenological phases it has. The Savo method was used to determine useful rain water. Adjustment and complementation of the irrigation program was based on indicators that characterize the exploitation scheme. The machine´s working parameters were determined to meet the water needs, and increase crop´s overall yields. The evaluations and results achieved have contributed to new proposals for management and operation of coil irrigation, and they are important to increase its efficiency.

KEY WORDS: sugar cane, *Saccharum officinarum*, coils, irrigation scheme, phenological stages

INTRODUCTION

Sugar cane plantations in Cuba cove more than 40% of crop lands, and sugar accounts for one of the first export items, along with other 50 derivatives (Jorge et al., 2010).

Sugar cane demands abundant and constant water supply for adequate growth and development. Under proper conditions, it grows in direct proportion to the

[1] Specialist in Irrigation and Drainage, Local Sugar Cane Research Station (ETICA) for the Mideastern Cuba, based in Camaguey, Cuba: jesus.sanchez@eticacm.azcuba.cu

[2] Associate researcher, Local Sugar Cane Research Station (ETICA) for the Mideastern Cuba, based in Camaguey, Cuba: yoslen@eticacm.azcuba.cu

[3]Specialist in Seed Production, Provincial Delegation of the Ministry of Agriculture (MINAG), Camaguey, Cuba: esp.iagric@cmg.minag.cu

[4]Researcher Provincial Delegation of the Ministry of Agriculture (MINAG), Camaguey, Cuba: esp.iagric@cmg.minag.cu

[5]Dr.C., Full Professor, Department of Agronomy, Ignacio Agramonte University of Camaguey: manuel.hernandez@reduc.edu.cu

[6]Director of Local Sugar Cane Research Station (ETICA) for the Mideastern Cuba, based in Camaguey, Cuba: a.noy@eticacm.azcuba.cu

amounts of water supplied; every 10 mm of water may represent 1 ton of sugar cane per ha (BSES, 1991).

The Cuban crop soils have unstable and insufficient levels of moisture to completely meet the plant´s water demands in its different stages (INRH, 2005). This situation is especially aggravated under the current conditions of drought that strikes the whole country. The usable water potential in Cuba is 38.1 km^3. And 70% is saved for crop irrigation. The current sugar cane irrigation area covers 65.6 thousand ha (AZCUBA - INICA, 2012).

Yearly rain distribution and frequency in Cuba is very irregular; therefore irrigation brings important benefits to sugar cane plantations, to increase yields to 40 t/ha, especially when the crop is properly attended (Reynoso, 1998). The first coil irrigation studies were developed at the Center for Agricultural Engineering, by Montero et al. (2009), in which adequate exploitation parameters for coil irrigation were determined for super dense plantain plantations. Additionally, a research project was designed to assess technical conditions of the equipment, under different production systems (2009). Montero et al. (2010) made an initial diagnostic to detect the main difficulties in the exploitation of coil irrigation, in different production scenarios.

Easiness and extended use in adverse conditions have stimulated farmers to use coil irrigation or traveling sprinklers in the province of Camaguey. The Local Station for Sugar Cane Research in the municipality of Florida acquired an electric coil irrigation system to meet the water needs of plantations in their different stages. It is one essential requisite for production of seed from different cultivars used in the region.

Effective irrigation is achieved when proper water amounts are supplied to the plants in their different growth stages. Adequate irrigation planning must take into account the standards, periods, and number of irrigation sessions to be applied along the plant cycle. These hydric requirements must be established for each of the crop stages, and they must be implemented in close relation with regulation of different working parameters for the coils. It must basically depend on a set irrigation schemes for exploitation.

The purpose of this work is to design an irrigation scheme for coils that helps meet sugar cane´s water demands in their different phenological phases, based on a previous irrigation scheme designed for a project and the existing edafoclimatic conditions.

MATERIALS AND METHODS

This study was made at the Basic Seed Bank of the Local Sugar Cane Research Station (ETICA), located on 21.31° north latitude, and 78.04° west longitude, 57.08 m above sea level (Agrometeorological Station, Florida, 2011). The predominant soil is brown with washed carbonate, according to the Cuban genetic soil classification (Hernández et al., 1975).

The prevailing climatic conditions in the area are characterized by mean temperature of 26.7° C; mean maximum temperature of 31.4° C; and mean minimum temperature of 21.6° C. The annual rainfall mean is 1236.78 mm, with 80% occurrence between May and October. Mean relative humidity is 75.6% (Agrometeorological Station, Florida, 2011).

The predominant wind direction is NE to E, and the highest frequency speed in the area was 10.8 km. This is an important element to consider for sprinkler irrigation, to keep soil moisture uniformity.

The system´s water supply for coil irrigation is ETICA mini-dam, which feeds Las Mercedes reservoir. Then the water is transferred to the pumping station that delivers the water to the system´s lines. Mini-dam capacity:

- Total volume: 98 000 m^3
- Useful volume: 95 000 m^3

The coilers used models were 110/250, with the following features:

- Hose length______________________________ 250 m
- Outer hose diameter____________________ 110 mm
- Inner hose diameter____________________ 94 mm
- Input pressure__________________ 5.0 bar
- Nozzle diameter________________________________ 22 mm
- Nozzle pressure_______________________________ 4.0 bar
- Consumption ____ 10.06 L/s
- Maximum reach radius___________________________ 41 m
- Wet diameter____________________________________ 66 m
- Carrier speed____________________ 18 m/h

The irrigation scheme for exploitation was determined according to the following elements:

- Apparent density (Ad) and field capacity (Fc)

Fc and Ad values were used as pondered mean to the depth of the humid layer, and according to the plant´s stage.

$$\text{Ad and Fc} = \frac{\alpha 1 * h1 + \alpha 2 * h2 + \ldots\ldots \alpha n * hn}{h1 + h2 + \ldots\ldots hn}$$

- Net partial standard (Nps)

Nps = 100 H Da (Fc – Lp)

Where:

H - Active soil layer to be humidified (m)

Ad - Apparent density (g/cm^3)

Fc - Field capacity (% PSS)

Pl - productive limit (80 % Fc)

- Gross partial standard (Gps)

$$Gps = \frac{Nps}{Ef}$$

Where:

Nps - Net partial standard (m^3/ha)

Ef - System´s efficiency (%)

System efficiency according to Resolution 21/99 INRH:

Irrigation technique	**Efficiency (%)**
Sprinkling:	
Low pressure	80
High pressure	**75**

- Crop evapo-transpiration (Etc)

ETc = ETo x Ck

Where:

ETc - evapo-transpiration or water demands of the crop (mm/day)

Ck - crop coefficient

ETo - reference evapo-transpiration (mm/day)

- Effectiveness coefficient (M)

M = m1 x m2

Where:

m_1 - slope, rainfall, and kind of soil

m_2 - active layer, rainfall and kind of soil

- Monthly usable rain water (Pacheco *et al.*, 2006)

Lla = M x Ll c

Where:

Us - Monthly usable rain water (mm)
Fr - Monthly fallen rain (mm)

- Moisture deficit

Hd = ETc – Us
Where:
Md-Moisture deficit (mm)
Us - Monthly usable rain water (mm)
ETc - crop evapo-transpiration (mm)
Number of irrigations (Ni)

$$Ni = \frac{Hd}{Nps}$$

Where:
Nps - Net partial standard (m^3/ha)

- Irrigation interval (Ir)

$$Ir = \frac{\text{Days of month}}{Ni}$$

Where:
Ir - Irrigation interval (days)
Ni - Number of irrigations

- Needed volume (Nv)

Nv = Gps x Ni x A
Where:
Gps - Gross partial standard (m^3/ha)
A – Land area (ha)

- Net hydromodule (nq)

$$nq = \frac{Nps}{3.6 * t * d}$$

Where:
Nps - Net partial standard (m^3/ha)
d - irrigation days
t - daily irrigation time

- Gross hydromodule (gq)

$$bq = \frac{Gps}{3.6 * t * d}$$

Where:
Gps - Gross partial standard (m^3/ha)
d - irrigation days
t - daily irrigation time

The elements below were applied to determine the electric coil working scheme, according to the exploitation conditions:

- Sprinkler carrier speed

The sprinkler carrier speed was determined to set the speed lever in the right position (according to the standard for corresponding speed).

$$S = \frac{600 \times Q}{Gps \times b \times KL}$$

Where:
S -Sprinkler or lateral moving speed (m/min) in (m/h)
600 - to transform (L to m^3)
Gps - Gross partial standard (m^3/ha)
Q - Pump flow (L/s)

- Irrigation strip width

$$b = 2 \times P \times R\max$$

Where:
b - Irrigation strip width (m)
P - 0.78 (for winds above or equal to 3 m/s)
Rmax.- Maximum reach radius (m) according to the manufacture´s charts

- Correction coefficient of irrigation strip length

$$LK = \frac{Ls}{Hl}$$

Where:
Lk - Correction coefficient of irrigation strip length
Ls - Irrigation strip length (m)
Hl - Hose length (m)

- Irrigation time in initial position (sprinkler carrier irrigation time without moving) (It) (h)

$$\mathbf{It} = \frac{2}{3} \text{ X } \alpha/360^0 \text{ X R/V}$$

Where:
α – angle of the wet sector
Rmax.- Maximum reach radius (m)
S - sprinkler carrier speed (m/h)

- Irrigation time moving in the strip (Mt) (h)

  Mt = Ls/S

Where:
Mt - Irrigation time in motion (hours)
Ls - Irrigation strip length (m)

- Irrigation time in final position (sprinkler carrier irrigation time without moving) (Ft) (h)

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$$Ft = \frac{2}{3} \text{ X } (1 - \alpha/360^0) \text{ X } R/V$$

- Irrigation time in the strip or position

$$Sit = It + Mt + Ft$$

- Mean intensity of application (mm/hour)

$$I = \frac{3600 \times F}{b \times S \times Sit \times K_L}$$

Where:
I - Mean intensity of application (mm/hour) (mm/h)
F - Flow L/s
b - Irrigation strip width (m)
S - Sprinkler carrier speed (m/h)
Sit - Irrigation time in the strip (hours)

Some economic indicators were determined for both irrigation schemes. The cost of water volume was used according to INRH cost records, with $18.00 per 1000 m3 delivered. The cost of power according to the rates set by OBE, at $0.84 per consumed KW.

The monthly evapo-transpiration values, and the crop coefficient values (Ck) for the province of Camaguey were achieved according to the Penman Fortieth method.

The Savo (Pacheco et al., 2006) method was used to determine usable rain water (ml includes soil features, the slope, and rainfall; and m2 comprises soil category, rainfalls, and root depth.

RESULTS AND DISCUSSION

Irrigation scheme for exploitation according to crop stages

Tables 1 and 2 show the results achieved for mean daily and monthly ETc from the beginning of shooting to the end of growth. The highest vales were observed in April for all the cases, coinciding with the dry season and greater water demand from the plantation. It is the time when the losses produced during evapo-transpiration must be restored by irrigation, which coincides with Fonseca and Pérez (2005), who noted that for this time of year the highest values of crop evapo-transpiration are produced. It has a negative influence on the number of active leaves, and leaf diameter and length, and therefore, on reduced stoma area, which hinders crop foliage development and premature field closing. The reference evapo-transpiration (ETo) indicators and crop coefficient (Ck) increase to a maximum value in the shooting stage, beginning to decrease at the end of the full growth stage; thus, when the water demand is greater, the coefficients increase.

Table 1. Daily crop evapo-transpiration (mm/d)

Phenological phases	Shooting	Field closing			Growth momentum					
Months	J	F	M	A	M	J	J	A	S	O
ETo*	3.6	4.2	4.4	4.8	4.3	4.0	4.4	4.4	4.2	4.1
Ck	0.50	1.03	1.03	1.03	1.05	1.05	1.05	1.05	1.05	1.05
ETc	1.8	4.3	4.5	4.9	4.5	4.2	4.6	4.6	4.4	4.3

Source: *Information provided by SIERIED (2012)

Table 2. Monthly crop evapo-transpiration (mm)

Phenological phases	Shooting	Field closing			Growth momentum					
Months	J	F	M	A	M	J	J	A	S	O
T (d)	30	28	31	30	31	30	31	31	30	31
ETc	54	120	139	147	139	126	142	142	132	133

Usable rain water determination by Savo (Table 3) helps corroborate that May has the highest rain water use value.

Table 3. Usable rain water by Savo

Months	J	F	M	A	M	J	J	A	S	O
Ll (mm)	7.5	6.9	18.1	185.6	323.4	138.8	240.6	161.8	216.3	150.4
m1	0.62	0.62	0.62	0.37	0.37	0.37	0.37	0.37	0.37	0.37
m2	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9
M	0.49	0.49	0.49	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Us (mm)	3.67	3.38	8.87	61.25	106.72	45.80	79.39	53.39	71.37	49.63

The irrigation scheme indicators (Table 4), according to the moisture deficit were determined by the proper water requirements for each crop stage, taking into account the humidifying depths in each. Note that the months with the greatest number of irrigations (February to April) comprise the second stage (shooting - field closing), coincidentally, the period with the highest water demand, and the highest ETc. Phenologically, the importance of irrigation in this stage owes to stem length and diameter increases. The population achieved in the previous stage will have a critical effect on production. Consequently, Vidal (2001) suggested that regardless of the edafoclimatic conditions, irrigation must be established at shorter intervals in this stage.

Table 4. Irrigation scheme indicators

Months	J	F	M	A	M	J	J	A	S	O
H (m)	0.25		0.30				0,35			
Md (mm)	50.3	116.6	130.1	85.7	32.3	80.2	62.6	88.6	60.6	83.4
Nps (mm)	20.9	25.0	25.0	25.0	28.5	28.5	28.5	28.5	28.5	28.5
Gps (mm)	27.8	33.3	33.3	33.3	38.0	38.0	38.0	38.0	38.0	38.0
Ni.	3	5	6	4	1	3	2	3	2	3
Ir (d)	10	6	5	7	31	10	15	10	15	10
S(m^3)	4014	9617	12021	7212	2743	8230	5487	8230	5487	8230
nq (L/s/ha)	0.72	1.44	1.44	1.44	1.66	1.66	1.66	1.66	1.66	1.66
qb (L/s/ha)	0.75	1.92	1.92	1.92	2.19	2.19	2.19	2.19	2.19	2.19

Concerning the growth stage, in which roots increase, it is important to step up the irrigation standard and intervals. Fonseca (1996) claimed that irrigation is more effective in the maximum growth period, especially three to five months following field closing, in the May - August period, when the soil must have proper humidity. Moreover, Humbert (1979) considered that irrigation frequency depends, among other factors, on the vegetative feature of sugar cane. As the root system penetrates deeper in the soil, the interval and standards to apply should be greater.

The irrigation scheme as a project (Table 5) is characterized by fixed values of Nps, Gps, Ni, and Ir, and refer to a single humidifying depth over the crop cycle, where efficiency was 85%, and the influence and intensity of sprinkler application regarding soil infiltration speed, was not taken into consideration. However, irrigation as a project (Table 5) showed that the previous indicators are distributed according to the stage the crop is, and to the different depths to humidify depending on the stage.

Table 5. Irrigation scheme for project and exploitation

Indicator	H (m)	Nps (m^3/ha)	Ef (%)	Gps (m^3/ha)	Ni	IR (d)	nq (L/s/ha)	bq (L/s/ha)	S (m^3)

Project	0.30	270	85	318	20	9	0.83	0.98	45 919
Exploitation									
Shooting	0.25	209	75	278	3	10	0.72	0.95	6021
Field closing	0.30	250	75	333	15	6	1.44	1.92	36 064
Growth momentum	0.35	285	75	380	14	15	1.66	2.19	38 410

Economically, (Table 6) the indicators for the project showed fixed values because they were set for all the plantation cycle. The exploitation scheme, however, included all the different plant stages, with the use of different Nps and Ni. The scheme for exploitation was observed to produce significant savings of water, which is more critical in the shooting stage. The relevance lies in that water can be used more efficiently, and the costs of water use in every stage may be cut down.

Table 6. Table 6 Economic indicators according to the irrigation scheme type

Stages/Indicators	Water volume (m^3)	Cost of water ($)	Pumping time (h, min.)	Cost of power ($)
Shooting:				
Project scheme	45 919.20	826.54	182.22	13 163.50
Exploitation scheme	6 021.48	108.38	23.53	1 726.15
Difference	39 897.72	718.16	158.32	11 437.35
Field closing:				
Project scheme	45 919.20	826.54	182.22	13 163.50
Exploitation scheme	36 063.90	649.15	143.11	10 338.32
Difference	9 855.30	177.39	39.11	2 825.18
Growth momentum:				
Project scheme	45 919.20	826.54	182.22	13 163.50
Exploitation scheme	38 410.40	691.38	152.42	11 010.98
Difference	7 508.80	135.16	29.47	2 152.52

It is important to highlight that reducing pumping time in every crop stage for exploitation has a significant effect on power cost savings, bringing benefits to the company. Furthermore, implementing such schemes at the Basic Seed Bank contributes to yield increases of approximately 20%, or 108 t/ha.

To make the equipment work properly, the operating parameters were determined, according to the exploitation conditions. Table 7 shows the results for different irrigation times for every working position (initial and final irrigation times without moving, and in mid position with sprinkler carrier motion), which set up the final irrigation time of the coil in the strip or position for every plant stage. At shooting, the irrigation times in the final and initial positions without moving account for 31 minutes; 36 in field closing for both; and 42 minutes for the last stage, respectively. The irrigation times are related to the working speed the equipment is set for each stage, and will depend on the length of the irrigation strip.

Table 7. Irrigation times (It) for each crop stage

Phenological phases	It. Initial position (h)	It. Movement (h)	It. Final position (h)	It. Strip (h)
Shooting	0.51	7.27	0.51	8.29
Field closing	0.60	8.38	0.60	9.58
Growth momentum	0.70	10.0	0.70	11.40

Different working parameters of coil in relation with different crop stages for irrigation (Table 8). The working speed (S) decreased as stages change and the gross partial standard increases. The opposite occurs to the strip irrigation time (Sit). Furthermore, the values of sprinkler application intensity (Si) are below the soil infiltration speed, which prevents flooding or draining in the surface. This soil type can be irrigated like that without danger of erosion, according to Pacheco et al. (2006).

Table 8. Working parameters of the irrigation equipment for each plant stage

Phenological phases	S (m/h)	Sit (h)	Si (mm/h)
Shooting	26.4	8.29	3.41
Field closing	22.2	9.58	3.49
Growth momentum	19.2	11.40	3.58

Equipment regulations needed for proper water supply, set for the exploitation scheme for irrigation (Table 9), according active soil layer depth to humidify. Accordingly, there is a relationship between water requirements of the crop and the coil working parameters (Tarjuelo, 2005).

Table 9. Exploitation parameters according to phenological phases

Phenological phases	h (m)	Gps (m^3/ha)	Position (speed lever)	Pressure (bar)	S (m/h)
Shooting	0.25	278	3rd	5.0	26.4
Field closing	0.30	333	3rd	4.6	22.2
Growth momentum	0.35	380	1rst	5.3	19.2

It is important that the coil operator knows and implements the established working parameters for the exploitation scheme, which will contribute to water and power savings; as well as an increase in basic seed quality and quantity for the Official Seed Banks in the province.

CONCLUSIONS

- The water requirements for the different phenological phases of the crop, according to the existing edafoclimatic conditions were determined.
- The project irrigation scheme was complemented with the results from the exploitation irrigation scheme, for further organization and implementation.
- The equipment working parameters were determined for the main water indicators required by the plants in every growth stage.

RECOMMENDATIONS

- ✓ To design an irrigation scheme for exploitation in all the official seed banks with coil irrigation technology in the province.
- ✓ To keep proper management and control of coil irrigation, through regulation of the equipment working parameters in every phenological phase of the crop, which is important to increase efficiency of this technology.

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