Performance assessment of furrow irrigation in two soils of different textures under high rainfall and field slope conditions

G. Ribas[1] and C. García[2]

Instituto Nacional de Colonización, Departamento de Riego, Dámaso Antonio Larrañaga 33, 50000, Salto, Uruguay[1].

Instituto Nacional de Investigación Agropecuaria (INIA). Programa de Producción y Sustentabilidad Ambiental. Estación Experimental INIA Las Brujas. Ruta 48 km 10, 90100, Rincón del Colorado, Uruguay[2].

Abstract

Furrow irrigation systems have been widely evaluated around the world. However, there is no national data indicating how efficient furrow irrigation is under Uruguayan conditions. Duran and Garcia Petillo (1980, data not published) show that efficiencies vary from 13 to 50%, but with control in water management and knowledge of soil water infiltration these values can be easily overcome. The objective of the present work was to evaluate the performance of a system of furrows irrigation in two soils of different texture. Twelve irrigation events were analyzed in sugarcane cultivation in northern Uruguay during 2016-17 . The water advance and recess curves were determined, flow rate during irrigation and runoff were monitored. The maximum furrow length studied was 100 m and the average slope was 0.24%. Efficiencies in both types of soils were observed above 75%. These field data were compared with data simulated by the WinSRFR model. Results of water application efficiency, distribution uniformity and runoff were correctly predicted. These first results encourage to continue working in the efficient use of the water, not only thinking about a better use of the resource but also in less loss by runoff and therefore less possibility of contamination and lower cost of energy and labor.

Keyword: furrow irrigation; water efficiency; irrigation evaluation; WinSRFR software

1. Introduction

Sugarcane (Saccharum officinarum) area cultivated in the world are 25 million hectares with an average yield of 70 t ha^{-1} per year (FAO, 2019). In South America commercial areas of sugarcane were observed irrigation application efficiencies of 59%, reaching values of 70% with water salinity management (Morabito et.al, 2007). In Australia application efficiency in commercial farms range between 31 and 62% with individual efficiencies that could be reach 90% (Raine and Bakker 1996).

Uruguay is located within the temperate zone of the southern hemisphere with climate characteristics: temperate, moderate, humid; warmest month temperature exceeding 22 °C (Koppen, 1918). The weather is characterized by high inter-annual, monthly and daily variability. Total annual rainfall ranges between 1100 and 1600 mm. There are not rainfall season but some years water deficit occurs from mid-spring to summer, during which evapotranspiration (ET) exceeds soil water available (Plan Nacional de Agua, 2017).

Agriculture, in Uruguay, is mostly rainfed, except for rice, intensive vegetables, citrus and sugarcane, where is carried out under irrigation by furrow (IICA, 2010). Sugarcane crop area takes place in the northwest of the country. Total area of this crop is 7.100 ha, with average sugarcane yield reaches 55.3 t ha^{-1} per year (DIEA, MGAP, average 2010-17). Traditional surface irrigation areas are rice and sugarcane crops, with low efficiency and high volume of freshwater consumed (Carnelli, 2010), so it is important to improve the efficiency of the water management because of this aspect is critical to ensure high productivity, decrease losses due to infiltration and runoff and can down the costs. The objective of the present work was to study the performance of the irrigation system by furrow in sugarcane through soil hidrophysics variables characteristics in each irrigation event.

2. Materials and Methods

2.1. Location of the experiment

The study was carried out in three sites, the Bella Union region of northeast Uruguay (30 ° 20 ' S; 57 ° 36' W and 120 m above mean sea). The soil on site I was fine, mixed, superactive, thermic Typic Argiudoll and site II was fine, mixed, superactive, thermic Pachic Vertic Argiudoll (Durán et al., 2005).

Initial soil samples were collected before starting the experiment in October 2016. Soil samples were collected at three different soil layers (0.0-0.20; 0.20-0.40 and 0.40-0.60 m) in each experimental site. Soil water retention curve was determined in the laboratory of INIA Las

Brujas using tension tables and pressure plates following procedure given by Richards and Weaver (1944). Bulk density was determined after saturation of the soil pores and adjustments for expansion by standard methods (Black, 1965). Water-holding capacity by volume at 0.01, 0.033, and 0.1 MPa was measured by the methods outlined by Richards and Weaver (1944). Textural class was determined by the international pipette method, measuring the percentages of clay, silt and sand in each soil layer studied (Day, 1965).

2.2. Crop management

The variety of sugarcane used was TUC 77-42, because of is the most planted in this region and there are more local research. The crop agronomic management were representative farm practice of the region (ALUR Sugarcane Industry instructive recommendation).

2.3. Irrigation management and soil water measurement

Irrigation evaluations were carried out in furrows with open end, furrow length 100 m or less and 1.2 m between rows. The average slopes recorded at each site were: 0.50% for site I and 0.24% for site II. During each irrigation event, three continuous furrows were selected to evaluate. The irrigation events were carried out in two irrigation seasons, 2016-17. Polytube were used to delivery water to the plot and gates were inserted every 2.40 m.
Applied depth irrigation were determined based on prior soil moisture content into root zone. Field irrigation evaluations were carried out according described by Morabito (2013). Flow rate was measure in each irrigation event at the beginning and at the end of the furrow with WSC flume (FAO, 1997). The data obtained are inflow rate and runoff. Determine infiltration with double ring NRCS-USDA were used in the head, middle and tail of each furrow. In addition, infiltration was determined by volume balance and adjusted by modified Kostiakov equation (1932). Total furrow length was divided into 10 stations in order to know advance and recession times. Profile of each furrow was determined following the methodology of the profilometer, Walker and Skogerboe (1987). Each measure was replicated three times along the furrow (head, middle and bottom). For each irrigation event irrigation depth to be applied at each site were calculated using the gravimetric procedure for the root exploration zone.

2.4. Statistical analysis

The variables studied were required application depth (dreq); total net irrigation (db); average depth of infiltrated water (infiltrated volume/area) (dinf); average depth of runoff, or, runoff volume expressed as an equivalent average depth (dr); infiltrated depth contributing to the irrigation target (dz). These variables allow to calculate AE (application efficiency): DE (distribution efficiency); EAL (storage efficiency); dz (percentage of deep percolation); Ep (percentage of runoff), as described by Bautista et al. (2012).

Infiltration of water in the soil, water holding capacity, irrigation time, advance and recession curve, uniformity of wetting in the soil profile and runoff in each of the applied irrigation were determined.

WinSRFR model (Bautista et al., 2009) were used to processed and analyzed irrigation events.

3. Results and Discussion

3.1. Description and analysis of soil

Soil characteristics of each site, soil type, depth of each layer, soil texture, bulk density, field water capacity, permanent wilting point and available water are presented in Table 1. Total available water for the root exploration zone (0.0-0.30 m) of sites I and II is 47.7 mm and 54.8 mm, respectively.

Table 1. Physical properties soils of three experimental sites.

Site	Soil	Horizon	Depth	Soil texture	Bulk density	Field Capacity	Permanent wilting point	Available water
			(m)		g cm^{-3}	% by volume		mm
I	Brunosol Subeutrico Luvico Mollisols (Udolls)	A	0.0-0.30	Sandy	1.36	18.7	7	11.7
		B	0.30-0.45	Sandy loam	1.50	22.0	13.0	9.0
II	Brunosol éutrico típicoVertisol (Uderts)	A	0.0-0.25	Loam	1.15	28.0	9.0	19.0
		B	0.25 - 0.40	Clay	1.35	26.3	13.0	13.3

3.2 Irrigation system

Table 2 shows the characteristics of furrows in each experimental site. Lengths ranged between 90 and 100 m and wide of each furrow was 1.2 m.

Table 2. Furrows characteristics

Variable	Site I	Site II
Length, L (m)	100-90	100
Width, W (m)	1.2	1.2
Downstream boundary	Open	Open
Cross - Section	Trapezoidal	Trapezoidal
Bottom slope So (m/m),	0.05	0.024
Mannign’s n	0.04	0.04
Inflow rate, Q (l/s)	0.5	0.5

Furrow shapes were trapezoidal and open end. Table 2 shows variables used into the model in each soil site. Manning's value used for both sites was 0.04 since the soil conditions were of low roughness and without the presence of weeds along the furrow.

3.3. Description and analysis of events

Performance indicators of each irrigation event in each site are presented in table 3. Irrigation depth varies from 19 to 41 mm according to soil water content in the root zone. It can be irrigation performance of the different events.

Table 3. Irrigation performance indicators from Site I.

Events	Required application depth (mm)	Application depth (mm)	Infiltrated depth (mm)	Runoff (mm)	Application Efficiency % * AE	Distribution Uniformity** DUlq	Opportunity Time (min.)***
1	17	20	18	4	78	0.86	79.3
2	17	23	20	3	75	0.82	86.0
3	17	23	20	3	75	0.84	76.2
4	23	41	35	6	56	0.88	140.0
5	23	19	14	5	77	0.91	76.0
6	23	39	39	1	58	0.67	78.0

*AE: Application Efficiency: Application Efficiency (AE = Dz / Dapp)

** DUlq: Low quarter average infiltrated depth average infiltration depth for quarter of the field receiving the least amount of water (not necessarily continuous).

*** Opportunity time: Difference between advance time and recession time along the furrow.

In the irrigation events 1, 2, and 3 observed better index of AE and application irrigation depth. The required application depth was 17 mm in events 1, 2 and 3 to reach field capacity, corresponding to 40% of the available water into the root zone of the crop. The depth irrigation applied for these first three events were on average 21 mm and average runoff 3.3 mm. Application efficiencies 76% (average) and distribution uniformity 0.84. Irrigation events 4 and 6, depth irrigation applied exceeded the required application depth, EA index down and the distribution uniformity in the low quarter increased. In the average of all irrigation events, high values were obtained of EA (69%) and DUlq 0.84. The average opportunity time was 98.6 min to replace required depth irrigation of 20 mm. At site I best performances were obtained applying 20 mm of irrigation depth. In this case required depth was 17 mm and flow rate 0.5 l s^{-1} reached application efficiencies 78% and uniformity of 0.78 with an opportunity time of 79 minutes.

The following figure (Figure 1) represent irrigation event 3 that shows hydraulic summary of this event. These data are based in field data and simulated data, irrigation required depth and infiltrated depth to replace requirement soil water.

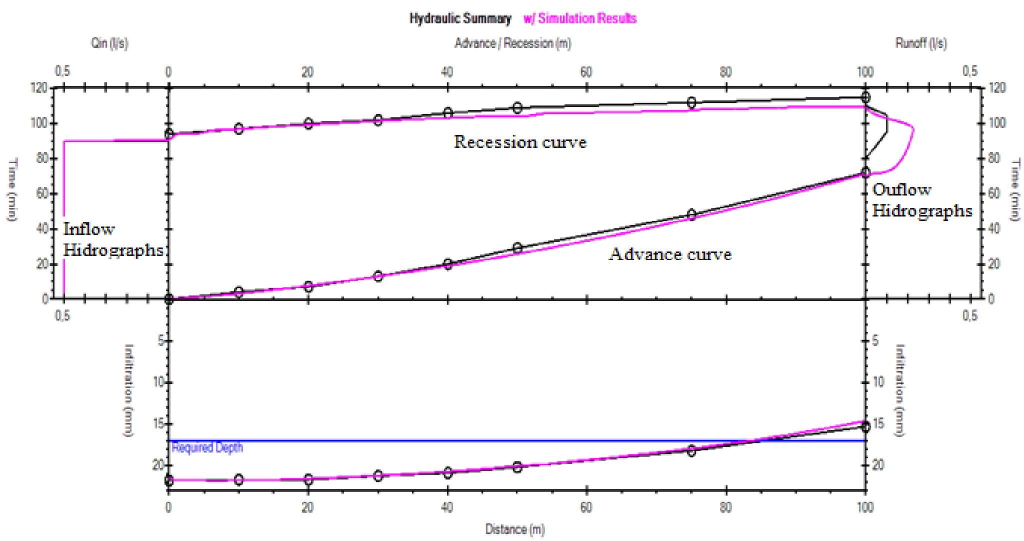

Figure 1. Hydraulic summary with field data and simulated data (irrigation 3).

*black line is observed data, rose line is simulated data, blue line is required depth irrigation.

As can be observed in figure 1 advance and recession curves are in the upper part of the figure. Observed data and simulated data matched very good. The area between advance and recession is the opportunity time (min.). In the low part of the figure blue line describe required irrigation depth and observed and simulated data of irrigation depth. It was observed good relationship reaching good performance.

At site II the soil was heavier which allowed a contrasting irrigation blade management to have different indicators of irrigation performance. The following table (Table 4) summarizes the main variables and index of performance irrigation on site II.

Table 4. Irrigation performance indicators from Site II.

Events	Required application depth (mm)	Application depth (mm)	infiltrated depth (mm)	Runoff (mm)	Application Efficiency % *AE	Distribution Uniformity ** DUlq	Opportunity Time (min.)***
1	30	33	29	4	87	0.83	105.7
2	30	33	32	2	86	0.76	112.0
3	30	38	34	4	77	0.81	131.4
4	18	20	14	6	72	0.93	106.0
5	18	23	17	6	75	0.94	95.0
6	18	20	14	7	68	0.94	98.0

* AE: Application Efficiency: Application Efficiency (AE = Dz / Dapp)

** DUlq: Low quarter average infiltrated depth average infiltration depth for quarter of the field receiving the least amount of water (not necessarily continuous).

*** Opportunity time: Difference between advance time and recession time along the furrow.

Required irrigation depth in 1, 2 and 3 irrigation events presented in table 4 were 30 mm, only in events 2 and 3 irrigation depth applied attended water requirements, however there was no possible in event 1. Average application efficiency was 83%, and average opportunity time 116 min.

In events 4, 5 and 6 it was not possible to attend required irrigation depth, runoff was 6.3 mm on average and application efficiency 71.6% and average opportunity time 100 min. A better uniformity of distribution was observed to the detriment of greater loss due to runoff.

In the average of 6 irrigation events for this site (site II), it was observed that application efficiency was 77% and the distribution uniformity of 0.87 for the fourth most affected.

The best performance of site II was obtained by irrigation depth of 33 mm when water required was 30 mm, runoff 4 mm and opportunity time 105 min. It was observed application efficiency 87% and distribution uniformity 0.73.

Data presented in figure 2 shows observed and simulated data infiltrated by Modified Kostiakov Infiltration equation on site II from irrigation event number 3. It can be observed good correlation along the furrow.

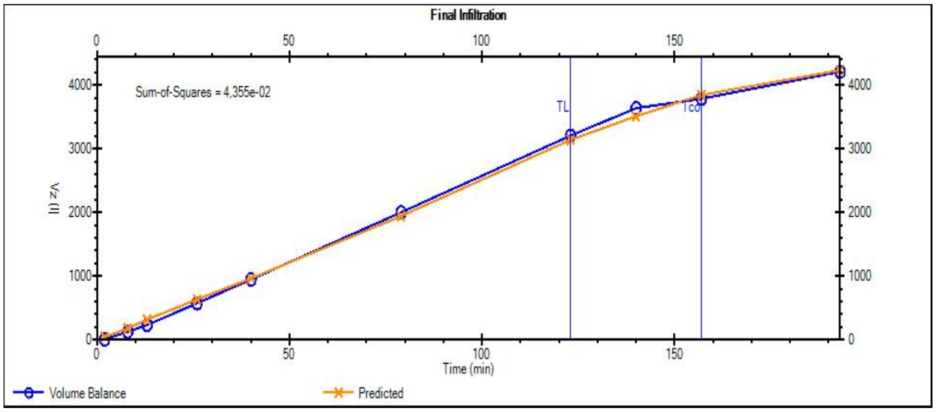

Figure 2. Infiltrated irrigation depth as function of time predicted with Modified Kostiakov Infiltration equation (irrigation event 3, sitio II).

In this figure (Figure 2) can be observed the adjust parameters of the infiltration function to match the predicted infiltration to the values derived from volume balance.

Conclusions

Application efficiency (AE) on site I was 70% and distribution uniformity (DU) 0.7. Applying required depth in most of the cases in 81.4 min in average (opportunity time), runoff was 3.5 mm in the average of all the events. The required average depth in site II was 24 mm, where it applied 27 mm and only 23.3 mm were infiltrated. Application efficiency was 77% and a distribution uniformity 0.8. Average runoff of irrigation events was 4.8mm. The WinSRFR model accurately predicted field experimental data. These results allows to conclude that high irrigation performances would be achieved, efficient water use and saving power and labor. It would be necessary to continue studying irrigation system performances to improve EA and DU in soils with different physics properties and different slopes.

References

Bautista, E., Clemmens, A.J., Strelkoff, T.S., Schlegel, J., 2009. Modern analysis of surface irrigation systems with WinSRFR. Agric. Water Manage., doi:10.1016/ j.agwat.2009.03.007.

Bautista, E; Schlegel, J.; Strelkoff, T. USDA 2012. WinSRFR 4.1 User Manual. U.S Departament of Agriculture, Agricultural Research Service. Arid Land Agricultural Reseach Center. 175 pp.

Black, C.A.; Evans, D.D.; Ensminger, L.E.; White, J.L. and Clark, F.E. 1965. Methods of soil analysis. American Society of Agronomy. Madison, Winscousin, Agronomy (ASA) n.9.

Carnelli, J.C. 2010. Riego en agroenergía predial. In: Primer Seminario Internacional, Paysandú, Uruguay. Potencial del Riego Extensivo en Cultivos y Pasturas. INIA, Montevideo, Uruguay. (11): 25-33 208 p.

Day, R.P. 1965. Pipette method of particle size anal-ysis. In: Methods of soil analysis. Agronomy 9.ASA USA.p. 553-562.

DIEA. (2016). Producción vegetal. En Anuario estadístico agropecuario 2016. Montevideo: MGAP. In http://www.mgap.gub.uy/sites/default/files/ encuesta_agricola_invierno_2016.pdf

FAO, 2019. Disponible en http://www.fao.org/countryprofiles/index/en/?iso3=BRA

IICA (Instituto Interamericano de Cooperación para la Agricultura). 2010. El riego en los países del Cono Sur. Capítulo: Situación del riego en Uruguay. Procisur/IICA: pp 95-102.

Kostiakov, A. N. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. Transactions Congress International Society for Soil Science, 6th, Moscow, Part A: 17-21

Köppen, W. 1918. Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt (Intento de clasificación climática en relación a las distribuciones vegetales.) Geogr. Zeitschrift, 6, 593-611, 657-679.

Morábito J., Mirábile, C. y Salatino, S. 2007. Eficiencia de riego superficial, actual y potencial en el área de regadío del río Mendoza (Argentina). Revista Ingeniería del Agua de la Universidad de Córdoba, España, Vol. 14, No 3. pp. 199-213. ISSN: 1134–2196.

Morábito J., 2013. Desempeño del riego por superficie en el área de riego del rio Mendoza. Eficiencia actual y Potencial. Universidad Nacional de Cuyo – Facultad de Ciencias Agrarias. Tesis de Maestria. 91 p.

Raine, S. and Bakker, D. 1996. Increased furrow irrigation efficiency through better design and management of cane fields. In: Proceedings of the Australian Society Sugar Cane Technologists. https://www.researchgate.net/publication/239533237

Richards, L.R. & Weaver L.A. 1944. Moisture retention by some irrigated soils as related to soil moisture tension. Journal of Agricultural Research, 69 (6), pp. 215-235.

Walker, W. and Skogerboe, G., 1987. Surface Irrigation: Theory and practice. Englewood Cliffs, NJ, USA: Prentice-Hall Inc. xiii, 386p.