ORIGINAL ARTICLE

Effect of the salinity of aqueous soil extract in sprinkler irrigation systems

Efecto de la salinidad del extracto acuoso del suelo en sistemas de riego por aspersión

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ABSTRACT: The National Institute of Water Resources promotes efficient water management in agricultural enterprises, based on the application of scientific research results. In spite of the investment made in the Laguna Blanca Agricultural Enterprise, there are still difficulties in making agricultural production sustainable, due to the low agro-productivity of the soils and the decrease in the efficiency of irrigation water use. For this reason, it is necessary to update, from the design of the installations, the operating parameters of the irrigation systems with centre pivot and reel machines. Based on the solution of two real case studies, the negative effects of the presence of salts in the soil solution on crop yields and on the sustainability of the supply sources involved in the irrigation activity are addressed. The hypothetical-deductive method was used to validate the convenience of considering salinity in the soil saturation extract at the design stage. As a result, the average pumping flow rate was identified as the design parameter that significantly influences the operation of these irrigation machines; the increase of this parameter infers the need to establish plot drainage systems to reduce the effects of soil saturation and the presence of salts in the soil solution.

Keywords: Irrigation Machines, Pumping Rate, Irrigation Efficiency, Soil Saturation, Salinity.

RESUMEN: El Instituto Nacional de Recursos Hidráulicos promueve la gestión eficiente del agua en las empresas agropecuarias, sobre la base de aplicar resultados de investigaciones científicas. A pesar de la inversión realizada en la Empresa Agropecuaria Laguna Blanca, aún persisten dificultades para hacer sostenible las producciones agrícolas, debido a la baja agroproductividad de los suelos y el descenso de la eficiencia en el uso del agua de riego, por ello se infiere la necesidad de actualizar, desde el diseño de las instalaciones, los parámetros de explotación de los sistemas de riego con máquinas de Pivote Central y Enrolladores. Se aborda, a partir de la solución de dos casos de estudios reales, los efectos negativos de la presencia de sales en la solución del suelo, sobre el rendimiento de los cultivos y en la sostenibilidad de las fuentes de abasto implicadas en la actividad del riego. Se empleó el método hipotético - deductivo, para validar la conveniencia de considerar en la etapa de diseño, la salinidad en el extracto de saturación del suelo. Como resultado se identificó el caudal medio de bombeo, como el parámetro de diseño que influye significativamente en la explotación de estas máquinas de riego; el incremento de este parámetro infiere la necesidad de establecer sistemas de drenaje parcelario para disminuir los efectos de la saturación de los suelos y la presencia de sales en la solución del suelo.

Palabras clave: máquinas de riego, caudal de bombeo, eficiencia de riego, saturación del suelo, salinidad.

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INTRODUCTION

Water and food security are closely linked. Agriculture is by far the largest consumer of water, accounting for about 69% of all withdrawals worldwide and more than 80% in developing countries. Reliable and sufficient access to water increases agricultural yields, providing more food and higher incomes in rural areas where three-quarters of the world's hungry people live. Not surprisingly, countries with the best access to water are often also those with the lowest levels of undernourishment FAO (2000)) cited by Baucells & Méndez (2004).

Soil and water are the two primary resources, not only of agriculture, but of all life on planet Earth. When water supplies are sufficient and soils are fertile, agriculture can sustain civilised human life, provided that the climate is favourable. FAO (1996) cited by Tarjuelo, (2005), they state that, on the other hand, the lack of the necessary water, even temporarily, prevents agricultural work and triggers food insecurity. Today, the world's population and food needs are increasing at an unprecedented rate, making it more difficult to increase water supply to farmers.

According to Palacios-Vargas (2021), under the current climatic conditions, characterised by the alternation of adverse natural phenomena as a direct consequence of climate change, agricultural production is significantly affected in most of the scenarios of use, and sometimes the agro-productive potential of the soil is not taken into account when selecting the irrigation technique to be used.

According to Vargas-Ferrer (2022), the simplifications that are made during the agronomic design of sprinkler irrigation systems with central pivot and irrigation systems with reels, lead to underestimate the water needs of crops, and leads to an installation more susceptible to problems of poor drainage and salinity, which persist in soils of agro-productive category III and IV, characteristic of the area under study (Barragan-Fernandez & Casañas-Cladellas, 1980).

In this sense, the research is carried out as a modest contribution that addresses the implications that the presence of salts in the aqueous extract of the soil has on the total water requirements of the crops and therefore on the operating parameters of mechanised sprinkler irrigation installations, specifically the Central Pivot machines and the Reelers.

According to FAO (2000) cited by Vargas-Ferrer (2022), the analysis of the selection of sprinkler irrigation facilities should include: The correspondence between the average rainfall intensity and the absorption capacity of the soil; the correspondence between the dimensions and configuration of the irrigated territory with the fundamental parameters and indices of the installations; the analysis of the climatic and topographic conditions of the territory (the complexity of the relief of the terrain, the slope and the physical-chemical properties of the soil), as well as the economic conditions and possibilities.

MATERIALS AND METHODS

Description of the study case

The study area occupies a total surface of 122.88 hectares in the Laguna Blanca Agricultural Enterprise, in the area known as Avocado, Contramaestre municipality, Santiago de Cuba province. It is proposed to irrigate a surface area of 51.78 ha with an electric central pivot to benefit the cultivation of plantain (CEMSA – variety) and a rectangular plot of 18.5 ha to benefit pasture crops for animal feed with reel irrigation techniques; the rest of the area will be irrigated using other sprinkler irrigation techniques.

The area belongs to UBPC No.1 "4 de abril", bordered to the South by the main canal, to the North by the secondary canal No.1 that supplies machines 3 and 4, to the East by an embankment that divides areas 1 and 3 of said UBPC and to the West by UBPC 2. The coordinates are: 195 000 - 197 000 North and 575 000 - 578 000 East, map sheet 4977-II-b-4 scale 1:10 000 of the ICGC.

Basic data for design

Source of supply

Availability and accessibility: The source of supply was the Cauto river, specifically in the place known as Arrollo Blanco, where there is a pumping station on the right bank of the Cauto river equipped with 6 pumps Q = 400 L/s and H = 784 kPa for a total flow of the pumping station Q = 2.4 m^3/s.

Water quality for irrigation: Water samples were taken at the supply source to determine its physical and chemical properties and were analysed in the laboratory of the provincial delegation of the INRH, verifying its suitability for irrigation of the proposed crops. For design purposes, a salinity in the irrigation water (CE_{AR} = 1.2 dS/m), corresponding to irrigation water of medium salinity was used to compare the variants (Pizarro, 1985).

Soils

According to the DSF-EALB-Santiago of Cuba (2006) report, the soil of both irrigation plots was classified as Dark Plastic Gleissy, yellowish-grey, on carbonate materials, medium humification (2 to 4 %), slightly eroded, of medium-clay texture, medium gleissy and slightly saline, with a uniform profile up to 0.7 m. It was not possible to measure the salt content in the soil solution in either case, but it was found during the technical visit that the soils have poor natural surface and internal drainage.

In both plots the following limitations were recognised: poor drainage, shallow effective depth and high plasticity. The following hydrophysical properties can be considered common to both plots.

TABLE 1. Hydrophysical properties of the soil, DSF-EALB-Santiago of Cuba (2006)

Infiltration rate	(Vi) = 26.0 mm/h (stabilized 50 min)
Field capacity	(CC) = 54.1 % PSS (high)
Productive limit	(LP) ≈ 80.0 % CC
Bulk density	(DA) = 1.02 g/cm^3

It was assumed for the design that the plot has a uniform profile up to 0.7 m with a medium-clay texture, the effective depth = 25 cm (shallow), the predominant slope slightly more than 1 % (flat). The recommendations for its use in banana cultivation stipulate planting in beds combined with the application of organic matter and a surface drainage system. In the case of the experimental plot for pasture cultivation, the soil of the plot has a uniform profile and medium texture with a slope of 2% and a storage capacity of 1 mm/cm of soil.

Crops

The crop to be cultivated with the central pivot irrigation machine was plantain (CEMSA –) with extra-dense technology. The following characteristics were taken into account: root depth 0.7 m, crop coefficient 0.75 potential yield 65 Tn/ha, an allowable management deficit = 40 % and tolerance to flooding of 1 to 2 days. In the case of the experimental plot, a hose reel was used for irrigation, the characteristics of which are given below. Grass crops with a root depth of 67 cm and a permissible management deficit of 55 % of the useful water will benefit.

Climate

In accordance with the Technical Report, it was assumed for the design of the central pivot (plantain donkey crop), peak needs of 7.5 mm/day, corresponding to the month of April, in the same way it was considered for the design of the plot to be irrigated with the roller, net peak water needs = 6.3 mm/d. A measured prevailing wind speed of Vv = 2.5 m/s is estimated for the area.

Characteristics of irrigation techniques

In the case of the Central Pivot, it was foreseen to stop irrigation at least 4 hours per day, coinciding with the peak hours of the electricity tariff, with no irrigation-free days, estimating that a water application efficiency of 90 % can be achieved.

1. Tower spacing 35m (short tower model), eaves length multiple 3m (max. 25m), pivot height 4m, lateral pipe diameter 200 x 189mm, AL, C150 - PN 6.
2. Sprinkler pressure rating 210 kPa and wetted width at the moving end 7m, maximum travel speed of the last tower 2.1 m/min.
3. It was decided to use a sprinkler (rotator) of medium size or smaller at its end located in a downpipe to leave it 2.5 m above the ground.

In the case of the Reelers, an irrigation efficiency of EAP = 75% was estimated, irrigation was also planned to stop during the hours of maximum electrical energy demand and up to two irrigation positions per day, separated by at least 1 hour to change from one position to the other, were used. A daily working day of 20 hours was assumed, the technical characteristics of the equipment are referred to in the design procedure.

According to Tarjuelo (2005), the Center Pivot design procedure includes:

Estimation of the length of the Pivot, number of towers and the length of the eaves:

The pivot was located on a square area of 517 800 m².

Being a square plot, the diameter of the circumscribed circumference to be covered by irrigation is equal to one side of the square (ϕ) = 719.6 m, therefore, the radius of the area to be irrigated by the Pivot will be:

$$R_{SR} = \frac{\phi}{2} \quad (1)$$

The number of towers will be:

$$N_{TORRES} = \frac{R_{SR}}{S/_{Torres}} \quad (2)$$

a machine with 10 towers of 35 m was designed, the remaining 9.8 m were covered with an overhang of 3 m, leaving 6.8 m to be covered by the final sprinkler whose wetted width is 7m.

The area of the circle irrigated by the machine will be:

$$A_{SR} = \pi \times R_{SR}{}^2 \quad (3)$$

as the total area of the table is 51.78 ha, 21.46 % of the plot would remain unirrigated.

Pivot capacity [Q_P (L/s)].

According to Tarjuelo, (2005), cited by Fernández-Hung *et al.* (2022) for irrigation of full cover crops, the following equation has been widely used:

$$Qp = 2{,}78 \times \frac{N_H \times A_{PR}}{T_{OD} \times Ef_{AP}} \times \frac{0{,}9}{(1-LR)} \quad (4)$$

Where:

the latter term is used when salts are present in the soil solution (when LR > 0.1).

Ef_{AP}- Application efficiency in the irrigation plot (decimal), is the fraction of water applied with irrigation that is retained in the root zone and available to the plant. Its value depends on soil type, irrigation technique and other factors.

T_{OD}- Daily operating time of the equipment (h), in the best case it is assumed as 90% of the hourly background to take into account possible interruptions in the peak period USDA (2013) and USDA-NRCS (2016), according to MFP-Cuba (2021) a daily operating time of 20 h was assumed.

LR- Represents the flushing requirements, its value depends on the electrical conductivity of the irrigation water [ECiw (dS/m)] and the electrical conductivity of the soil saturation extract [ECse (dS/m)] (CEN, 2013). According to Keller & Bliesner (1990), the term 0.9 is included to take into account the unavoidable percolation losses and assuming that these meet 10% of the flushing requirements, so that 90% of the production is guaranteed due to inappropriate soil saline contents, these authors propose: $LR = \frac{ECiw}{5(ECse - ECiw)}$, for sprinkler and surface irrigation systems. More recently USDA-NRCS (2016) propose;

$$LR = 0{,}18 \times \left(\frac{ECiw}{ECse}\right)^3 \quad (5)$$

Where:

used for high frequency irrigation and represents the limit of salinity in the root zone that the crop can tolerate without affecting the maximum potential yield.

N_H- It was assumed for the month of maximum needs of the banana crop according to the Technical Task, which was April 2 325 m^3/ha = 7.5 (mm/d or L/m^2/d):

Timming irrigation

The time required for the lateral to make one revolution [T_{MIN} (h)] depends on the maximum travel speed of the last tower [V_{MAX} (m/min)] and the perimeter to be covered, the maximum speed being set by the manufacturer according to the characteristics of the gearbox in the transmission mechanism. It was obtained from:

$$Tmín = \frac{2\pi * Rut}{Vmáx} \quad (6)$$

To determine the maximum time to complete a turn [$T_{MÁX}$ (h)], it was first necessary to estimate the minimum forward speed at which runoff begins to occur at the end of the pivot, according to Dillon *et al.* (1972), the calculation procedure followed the methodology proposed by this author, recommended by Tarjuelo (2005), in which the maximum rainfall at the end of the pivot [$P_{MÁX}$ (mm/h)] is obtained, as a function of the capacity of the pivot (L/s), the radius of the irrigated surface (m) and the wetted width at the end of the machine [AM (m)], taking into account the texture and slope of the soil, [T_M (h)] is determined, the maximum time that the equipment can take to pass over a point on the ground (from when it starts to wet it until it stops) so that there is no runoff:

$$P_{MÁX} = \frac{28800}{\pi} * \frac{Qp}{Rsr * AM} \quad (7)$$

from 3.2, for a loam soil, 1% slope and estimated surface storage of 7.6 mm, was obtained: $T_M \approx 0.51$ h = 30.6 min. Thus, the minimum equipment travel speed for no runoff was obtained by means of:

$$Vmín = \frac{AM}{T_M} \quad (8)$$

The maximum time the machine will take to complete a lap will be:

$$Tmáx = \left(\frac{2\pi * Rut}{Vmin}\right) \quad (9)$$

Gross and net doses, average applied dose, limits on frequency of application.

The highest average gross dose that can be applied without risk of runoff will be the one corresponding to $T_{MÁX}$, and the minimum average gross dose will be obtained as a function of $T_{MÍN}$, multiplying them by the application efficiency, the corresponding net doses will be obtained, the following expressions solve these parameters:

$$Dbmáx = 0.36 * \frac{(Qp * Tmáx)}{Asr} \quad (10)$$

$$Dbmín = 0.36 * \frac{(Qp * Tmín)}{Asr} \quad (11)$$

$$Dnmáx = Dbmáx * Efap \quad (12)$$

$$Dnmín = Dbmín * Efap \quad (13)$$

The limits of the maximum and minimum irrigation frequency were obtained by:

$$IRmáx = \frac{Dn\ \ máx}{NH} \quad (14)$$

$$IRmín = \frac{Dn\ \ mín}{NH} \quad (15)$$

The pressure required at the inlet of the pivot was determined by means of:

$$Hpiv = Hasp + Hfpiv + \Delta Zpiv + hpiv \quad (16)$$

Where:

H_{PIV} → Pressure required at pivot inlet (mca).

H_{ASP} → Nominal pressure of the last sprinkler.

Hf_{PIV} → Pressure loss due to friction in the pivot pipe (m).

ΔZ_{PIV} → Geometric difference in level between the pivot point and the end of the pipe.

h_{PIV} → Height of the pivot pipe above ground.

The head loss along the pipe was determined using the equation proposed by Chu *et al.* (1980).

$$Hfpivo = 0.548 \times Hm \quad (17)$$

Where:

Hm→ Obtained by the William-Hazen expression assuming intermediate turbulent regime.

The design procedure for the Reelers was taken from the same author:

Calculation of irrigation parameters:

The net irrigation dose [D_N (mm)] was calculated as a function of the soil storage capacity [CA (mm/cm)], the depth to be wetted [Z (cm)] and the allowable moisture deficit [DPM (decimal)], as follows:

$$D_N = CA \times Z \times DPM \quad (18)$$

- The gross dose to be applied [D_B (mm)] was estimated according to the water losses occurring in the plot, as well as those occurring in the water conduction and distribution system, which are valued through the Irrigation Efficiency [E_R (decimal)], by:

$$Db = \frac{D_N}{Efap} \quad (19)$$

- The maximum irrigation frequency [IR_{MAX} (days)] was obtained from the quotient of the net irrigation rate and the net water requirement of the crop, which was assumed to be 6.3 mm/d as recommended by the Technical Task:

$$Irmáx = \frac{D_N}{N_H} \quad (20)$$

its value was set to an integer number coincident with the number of bands in the plot [E (m)].

Required average pumping rate [Q_P (L/s)].

As in the case of the Pivot, it was calculated as the quotient between the volume of water that needs to be applied to the plot in one irrigation and the number of hours needed for this purpose, as it is also an irrigation option that delivers water in motion, the same explanations apply:

$$Qp = 2{,}78 \times \frac{N_H \times A_{PR}}{T_{OD} \times Ef_{AP}} \times \frac{0{,}9}{(1-LR)} \quad (21)$$

Given the possibility of days with strong winds (Vv ≥ 4 m/s) on which it would be advisable not to irrigate, many manufacturers recommend increasing the flow rate of the equipment by between 15 and 20%, leaving a safety margin to be able to benefit crops with greater demand and in the event of breakdowns. However, design practice establishes that, when considering 20 h of irrigation and not 24 h, the flow rate is increased by more than 25%, more than satisfying this recommendation Tarjuelo (2005).

Sprinkler selection

It was selected according to the average pumping flow (m3/h) and the range of maximum and minimum pressures in which the sprinkler works best. The catalogue published by Tarjuelo (2005) was used to assume the main characteristics of the sprinkler, which are shown in the following table:

Maximum sprinkler rainfall [P_{MAX}(mm/h)]

Obtained as a function of the sprinkler discharge and the area it wets and should be less than or equal to the stabilised infiltration rate of the soil to avoid water loss through runoff and/or deep percolation.

$$Pmáx = \frac{Q_{asp}}{\pi(0.9 \times Rasp)^2 \left(\frac{(\sphericalangle sr)^\circ}{360^\circ}\right)} \quad (22)$$

it was found that this sprinkler will not cause surface runoff problems on bare soil. 90% of the sprinkler's radius of throw was considered, to take into account that ($P_{MÁX}$) falls over most of the wetted area, over a surface area greater than the average wetted value Keller & Bliesner (1990).

Spacing between irrigation positions

A prevailing wind speed (V_V = 2.5 m/s) was assumed, this infers that ≈ 68 % of the wetted diameter is wetted by the sprinkler, from this, the bandwidth or separation between irrigation positions was obtained by:

$$E = 2 \times Rasp \times \%mojado \quad (23)$$

the equipment was planned to be placed in the shortest dimension of the irrigation plot in order to reduce the displacement of the hose from the Reeler and consequently the friction losses that occur, and the band width was also planned to be of full dimensions and the total number of bands to coincide with 6.3.

Sprinkler ground speed [V_{AV} (m/h)]

$$V_{av} = \frac{Qasp}{Db \times E} \quad (24)$$

it was found that the value obtained was within the permissible range according to the manufacturer (between 5 and 50 m/h).

Irrigation timming

The time required to irrigate one position [T_R (h)], depends on the length to be covered and the forward speed. The operating time at the beginning and at the end of the plot was also taken into account, as well as the forward time, and the convenience of carrying out two irrigation positions per day. The calculation included:

TABLE 2. Main characteristics of the selected sprinkler, Tarjuelo (2005)

Sprinkler pressure (H_{asp})	405.3 kPa	Outlet diameter (ϕ_{boq})	32 mm
Sprinkler Flow Rate (Q_{asp})	78.7 m^3/h	Angle irrigated sector ($\sphericalangle sr$)	220°
Sprinkler Radius (R_{asp})	52 m	Outlet Angle ($\sphericalangle s$)	22°
Pipe Diameter (ϕ_{mang})	110 mm	Reeler height (h_E)	3.15 m
Pipe length (L_{mang})	260 m	Local losses (Hf_{loc})	98 Pa

The distance at the start [D_{INI} (m)] between the end of the plot and the starting position of the Reeler was obtained by:

$$Dini = \frac{2}{3} \times Rasp \quad (25)$$

The duration of irrigation in the initial position of the equipment [T_{INI} (h)]:

$$Tini = \frac{2}{3} \times \frac{(\sphericalangle sr)^\circ}{360^\circ} \times \frac{Rasp}{V_{av}} \quad (26)$$

The duration of irrigation at the end position of the equipment [T_{FIN} (h)]:

$$Tfin = \frac{2}{3} \times 1 - \frac{(\sphericalangle sr)^\circ}{360^\circ} \times \frac{Rasp}{V_{av}} \quad (27)$$

The duration of irrigation during the run from the end to the beginning of the plot [T_{AV} (h)] and where the run length (L_{MANG}) resulted, in this case, from the difference between the half of the irrigated plot and (D_{INI}):

$$Tav = \frac{Lmang}{V_{av}} \quad (28)$$

The total duration of irrigation in one position resulted:

$$T_R = Tini + Tav + Tfin \quad (29)$$

was assumed up to 1h duration for the change from one position to another of the equipment [T_C (h)], therefore the first irrigation session (in the morning), was obtained by adding up: $T_R + T_C$.

The pressure required at the hydrant supplying the Reeler was obtained by adding to the working pressure of the sprinkler given in the manufacturer's catalogue [H_{asp} (mca)], its height above ground [h_E(m)], the most unfavourable topographical slope [ΔZ_E (m)] and the hose friction losses [Hfmang (mca)], as well as the local losses [Hfmang (mca)], the most unfavourable topographical slope [ΔZ_E (m)] and the friction losses in the hose [Hf_{mang} (mca)], as well as the local losses [Hf_{loc} (mca)] that occur in the propulsion and regulation mechanisms, the expression was as follows:

$$H_H = Hasp + hfmang + \Delta Z_E + hfloc + he \quad (30)$$

RESULTS AND DISCUSSION

Design references (Tables 3 y 4, Figures 1 y 2)

When the quality of the information on the Water - Soil - Plant - Climate complex and the characteristics of the irrigation technology, including the performance of the pumping equipment, is guaranteed in a timely manner, it is possible to foresee during the design stage possible solutions to be faced by the personnel dedicated to the operation of the facilities.

It was necessary to know the availability and quality of the water supply source in order to compare it with the annual needs of the installations, this made it possible to check the relevance of the irrigation techniques, the accessibility of the water supply source in order to verify the pumping performance of the installation, and to verify the quality and availability of the water supply source.

The suitability of the soils for irrigation of the proposed crops was taken into account, Ayers & Westcot (1987) presented information on the tolerance of plants to salinity, based on data obtained by several authors and the recent Mass-Hoffman data, the latter proposed a formula relating the production of different crops to soil salinity.

By applying the Mass-Hoffman formula to the large amount of data collected by Ayers & Westcot (1987), the values of resistance and sensitivity to salinity of different crops were determined. This led to the assumption of salinity value in the aqueous soil extract corresponding to 100% production of the crops to benefit in each case, a CE_{ES} = 1.0 dS/m was assumed for the comparison between the variants, due to the presence of saline in the soil, corresponding to a 100% production guarantee (Pizarro, 1985). It was also of interest to know the stabilised infiltration rate and the time at which it stabilises, the depth of the active layer, the texture and the relief in order to prioritise the design of a surface drainage system and to be able to estimate a washing dose that will enable maintenance washing to be programmed in the short term, together with irrigation.

Regarding the crops, it was convenient to know the planting frame and sowing direction, the root depth, the crop tolerance to flooding and salinity, as well as the crop coefficient in the three main phases in order to be able to monitor the water needs of the crops during the irrigation management in the facilities. For the purpose of irrigation system design, these were assumed in accordance with the Technical Task.

ANALYSIS OF THE RESULTS

A Central Pivot was designed to deliver a flow rate = 47 L/s, with a necessary pressure at the machine inlet of 32 mca, with the possibility to complete a rotation between 17.45 and 40.5 hours, without surface runoff occurring. As this is an irrigation technique that delivers water to the moving plants and the storage capacity of the soil is not homogeneous throughout the soil profile and the maximum gross dose is high (16.88 mm), it is recommended during irrigation water management to predict the timing of irrigation according to the soil moisture content.

As irrigation will be applied every two days, it is advisable to divide the plot into two equal halves, each of which will be irrigated for a full irrigation day (20 hours with a double shift), taking into account the permissible moisture deficit to avoid run-off. In the case of the variant with the presence of salts, as the average pumping flow rate increases, the maximum irrigation frequency decreases and therefore a more restricted installation is designed, making it more complicated to partition irrigation, without applying automatisms to programme irrigation, as the maximum irrigation frequency was 1.76 days.

TABLE 3. Results of the agronomic design of the Central Pivot

Design parameters	Present of salts.	No salts present.
Number of tower.	10	10
Irrigated area.	40.6 ha	40.6 ha
Machine Capacity.	61 L/s	47 L/s
Maximum velocity of pivot.	2.1 m/min	2.1 m/min
Minimum time for one rotation.	17.45 h	17.45 h
Maximum discharge rate.	224 mm/h	171 mm/h
Maximum time to wet one point.	0.09 h	0.13 h
Minimum velocity of pivot.	1.36 m/min	0.9 m/min
Maximum time for a rotation.	27.02 h	40.5 h
Maximum gross deep.	14.71 mm	16.88 mm
Minimum gross deep.	9.50 mm	7.27 mm
Maximum net deep.	13.24 mm	15.19 mm
Minimum net deep.	8.55 mm	6.54 mm
Maximum irrigation frequency.	1.76 d	2.03 d
Minimum irrigation frequency.	1.14 d	0.87 d
Friction losses.	35.49 kPa	21.57 kPa
Pressure head in the Central Pivot.	318 kPa	312 kPa

TABLE 4. Results of the agronomic design of the Reeler

Design parameters.	Present of salts.	No salts present.
Adjusted net deep	25.2 mm	31.5 mm
Adjusted gross deep	33.6 mm	42.0 mm
Maximum irrigation frequency.	4 d	5 d
Reeler discharge	111 m^3/h	78.7 m^3/h
Maximum discharge rate.	18.5 mm/h	18.7 mm/h
Bandwidth	88.5 m	71 m
Number of bands	4 bands	5 bands
Equipment feed velocity	37.22 m/h	26.4 m/h
Irrigation time in the initial position.	0.68 h	0.7 h
Irrigation time in the final position.	0.43 h	0.4 h
Equipment lead time	5.89 h	8.4 h
Timming irrigation.	7.0 h	9.5 h
Friction losses.	223.8 kPa	116.5 kPa
Hydrant pressure.	1002 kPa	693.5 kPa

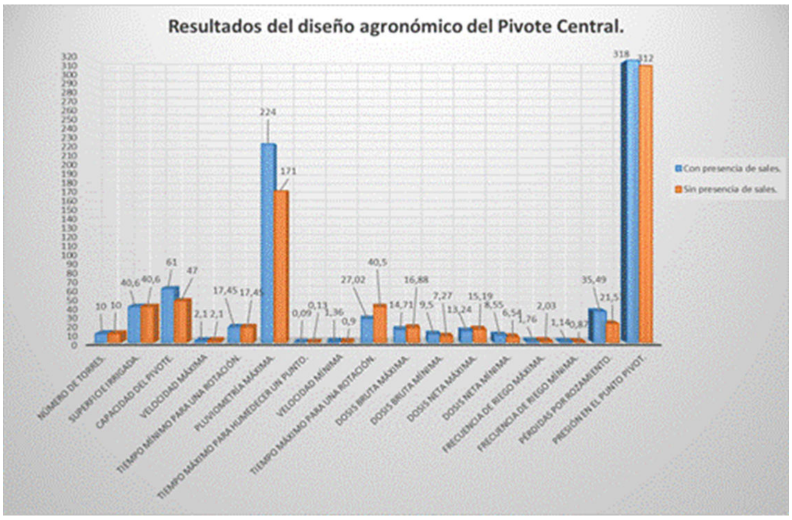

FIGURE 1. Behaviour of the design parameters of the Central Pivot.

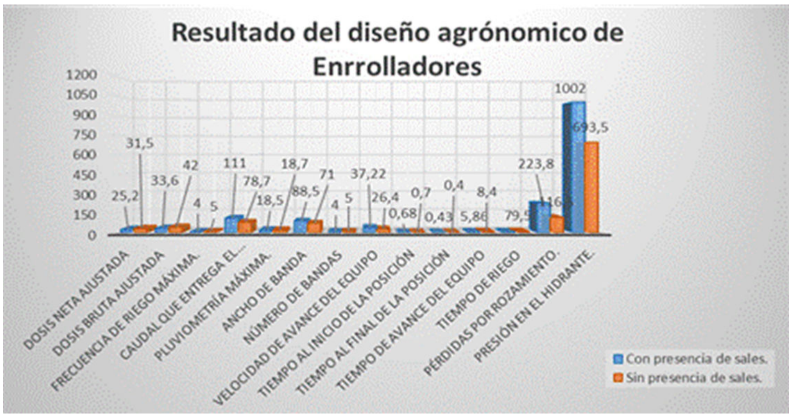

FIGURE 2. Behaviour of the Reeler design parameters.

A Reeler with an irrigation cannon discharging 22 L/s with a pressure at the base of 42 mca was selected, as a result of the design the plot was divided into 5 bands of 355 m each. The irrigation day includes two daily positions, each one was conceived for an irrigation time of 9h and 30 min, and up to one hour was planned for the change from one position to another.

From the pressure required at the hydrant and applying the Bernoulli and Continuity equations, it was possible to obtain the pressure required at the valve at the entrance to the plot, the value of which was approximately 70% of that which occurs in the variant with the presence of salts, very similar to what happens with the average pumping flow required to irrigate the plot.

In the design of the variant with the presence of salts, the flow rate to be applied was increased by 30 %, however, the adjusted gross dose to be applied during irrigation decreases by 20 %, this is due to the fact that, as with the central pivots, these irrigation machines also deliver the water in movement. In any case, it is necessary to check the moisture content of the soil during operation, as over-wetting or saturation of the soil will facilitate the negative effect of salts in the aqueous layer of the soil.

Effects of salinity on the soil aqueous layer

The main design parameter influencing the modification of the operation of both irrigation equipment is the average pumping flow rate that needs to be ensured for the application of the irrigation doses. As it has already been shown, when taking into account the leaching requirements by equations (4) and (21), the flow rate was increased by 23 % for the centre pivot machine and by 30 % for the Reeler machine, the consequences can be significantly negative for the sustainability of the installation.

As the surface to be wetted is the same, in the case of the centre pivot machine, the rainfall also increases, this situation implies the need to foresee possible excesses of moisture in the effective soil profile and can make the movement of the irrigation machinery more difficult, as surface irrigation losses are increased, as well as the risk of soil saturation and the harmful effect of salts, this situation infers the need to ensure surface drainage solutions in the irrigation system.

In the case of the Reeler irrigation system, this situation is different since numerically the rainfall value remains very similar in both cases; However, this situation, which in principle seems contradictory, is explained because in this case the increase in the average pumping flow rate led to the selection of another flow emission device with other features (greater radius of reach and greater pressure required for its operation), this led to an increase of ≈ 20 % in the surface area to be irrigated in each position and for this reason both rainfall values are similar, but this does not mean that the saturation irrigation of the effective soil profile is eliminated.

The fact of increasing the volume of water applied in a 2.5 hours shorter irrigation time, infers an equally important risk of over-wetting of the soil due to irrigation, with the consequent negative effect of the presence of salts in the productive soil profile.

The irrigation duration between the two variants does not present differences that cannot be assumed during operation, however, in the case of the centre pivot, the design with the presence of salts in the soil solution leads to a significant decrease in the maximum time to complete a round.

CONCLUSIONS

Salinity in the soil aqueous extract has negative effects on crop yields, affecting water productivity on farms, estimating flushing rates during design contributes to decrease the negative effect of salts in the soil solution.

Increasing the volume of water to be applied to crops, taking into account the salinity of the irrigation water and the saturation extract of the soil, may not necessarily increase the irrigation duration in mobile sprinkler irrigation installations, due to the particularity of delivering the irrigation dose on the move.

The deficient natural drainage and the absence of surface drainage systems condition the presence of harmful saline contents in the agricultural soils of the Laguna Blanca Agricultural Company.

Irrigation systems have yet to be installed on a significant agricultural area of the Agricultural Company Laguna Blanca, which implies the need to apply criteria for the selection of irrigation techniques, using appropriate basic information as a valid option to increase the value of use of the Company's supply sources.

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