ORIGINAL ARTICLE

Irrigation Management with Medium Salinity Water in the Cabacú Protected Crops House

Manejo del riego con aguas de salinidad media en la Casa de Cultivo Protegido Cabacú

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ABSTRACT: The movement of the tides on the north coast of the Baracoa city affects the water quality in the supply source for the irrigation of Cabacú Protected Crops. This situation reduces the agro productivity of the soil, the quality and yield of the crops and leads to the establishment of a procedure for the management of irrigation, taking into account the movement of the tides. In this sense, the agronomic parameters of the drip irrigation system were determined, as well as the necessary leaching dose to maintain appropriate salinity levels for the crops. As a result, a procedure was established for the management of the irrigation system with saline water that contributes to increase the quality and crop yields highly valued by the inhabitants of the Cabacú Popular Council.

Keywords: Irrigation Deep, Leaching Dose, Saline Intrusion, Leaching Water.

RESUMEN: El movimiento de las mareas en el litoral norte de la ciudad de Baracoa afecta la calidad del agua en la fuente de abasto para el riego de la UEB Cultivo Protegido Cabacú, esta situación disminuye la agroproductividad de los suelos, la calidad y el rendimiento de los cultivos y conlleva a establecer un procedimiento para el manejo del riego, teniendo en cuenta el movimiento de las mareas. En este sentido, se determinaron los parámetros agronómicos del sistema de riego por goteo, así como la dosis de lavado necesaria, para mantener la salinidad en niveles apropiados para los cultivos. Como resultado, se estableció un procedimiento para el manejo del sistema de riego con aguas de salinidad media que contribuye a incrementar la calidad y el rendimiento de cultivos altamente valorados por los pobladores del Consejo Popular Cabacú.

Palabras clave: dosis de riego, dosis de lavado, intrusión salina, agua de lavado.

INTRODUCTION

According to Van Hoorn (1979) and Van Alphen (1983), quoted by Ritzema (1994), the application of irrigation water involves the input of salts into the soil; even if the irrigation water is of excellent quality, it is considered to be the main source of soluble salts in the soil. Whenever the aim is to avoid soil salinization, the solution involves leaching salts from the root zone using the percolation capacity of the soil. However, percolation water leads to a rise in the water table, resulting in the second source of soil salinization, which is why drainage solutions must complement the leaching and recovery programs of saline soils, especially in humid regions with warm climates.

The research was carried out in the UEB Casa de Cultivo Cabacú, whose social purpose is the production of vegetables to supply tourism and the population of Cabacú Council (Matos, 2017). It was found that the presence of inappropriate salt levels affected agro-productivity of the substrate and crop yields. This situation is aggravated by the poor quality of irrigation water, due to the influence of saline intrusion in the supply source. This is caused by a wedge of seawater, which penetrates 1 km into the river and whose electrical conductivity has been measured at 3.6 dS/m.

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Yellowish colorations were observed on the cucumber crop due to (Mg) deficiencies, as well as a black color on the tomato plants (Culillo del Tomate) due to (Ca) deficiencies. This salt wedge is linked to tidal movement; this percolation leads to an elevation of the tide pH, where values ≥ 10 were measured, which contributed to the continued occurrence of tomato leaf scorch, curling and leaf scorch, demonstrating the high concentration of salts that negatively influences crop growth and development. For these reasons, the obtained yields of 7 Ton/ha are lower than the expected of 12 tons per farmhouse.

Despite changing the substrate and applying sowing in bags and in beds improved with organic matter, the problem caused by the use of poor quality irrigation water has not been solved; on the contrary, the level of salinization of the substrate has increased. This situation calls for measures to be taken during management to help recover yields by recovering substrate properties and preventing contamination, improving the quality of irrigation water and establishing leaching standards together with the irrigation dose to maintain the desired yields. These arguments lead to the assertion that: Tidal movement on the north coast of Baracoa City affects the quality of water for irrigation in the UEB Casa de Cultivo Cabacú, affects the agro-productivity of the substrate and causes a decrease in crop yields (Figure 1).

The solution involves programming a leaching process to recover the substrate quality and establishing a procedure for the management of the drip irrigation system with medium saline water, based on the behavior of the moon phases. That implies:

- Reviewing the current state of the art referred to the methods of leaching and recovery of saline soils, with emphasis on the management of irrigation with medium saline waters.
- Characterizing the study case.
- Determining the leaching doses for the recovery of the substrate and maintaining its quality.
- Calculating the agronomic parameters of the irrigation system.
- Proposing measures for the management of the drip irrigation system, considering the movement of the tides.

Bibliographic review

The mineralization of saline water depends on climatic and hydrogeological factors; rainwater leaching eliminates salts from the root zone; evapotranspiration consumes water, but does not eliminate salts, increasing the saline concentration of the water. Where salinizing factors predominate over leaching factors, the groundwater will become mineralized ((Pizarro, 1985) quoted by Martínez , 2001). According to this author, when saline groundwater is close to the surface (≤ 3m), it can become saline as a result of the capillary supply of salts, which, once accumulated, remain in the soil solution, damaging the development of crops (Pizarro, 1996).

When the sodium content is high in relation to the other cations, this element can be absorbed by the exchange complex in excessive quantities, dispersing the clay particles and weakening the structure and permeability of the soil. This is generally the process of soil salinization, and the nature of the salts depends on the origin of the water.

Salinity Effects on Soil and Crops

According to Martínez (2001), the effects of soil salts can be summarized as follows:

1. Osmotic effect of dissolved salts.
2. Effects of adsorbed sodium.
3. Toxicity of some ions.

The presence of dissolved salts in the soil solution requires a greater plants effort to absorb water and nutrients, this effort means that part of metabolic energy of the plants is used for water absorption, in detriment of other functions that also require energy, such as growth and flowering. The higher the salt concentration of the soil water, the higher the osmotic pressure the plants have to overcome, and there may come a time when water uptake stops. For this reason, salinity symptoms coincide with drought symptoms and this explains the apparent paradox that plants experience drought on land with an abundance of saline water (Pizarro, 1985).

Martínez (2001) refers to Pizarro (1985), who recognizes the usefulness of the information compiled

FIGURE 1. Effects of salinity on crops, Matos et al (2017).

by Ayers and Ayers & Westcot (1987), which allows estimating plant tolerance to salinity, by means of an equation derived from data obtained from the US Salinity Laboratory and other authors, including Maas and Hoffman (Van Hoorn, 1981). These authors found that there is a linear relationship between soil solution salinity and crop production and proposed a formula relating a percentage of the production of different crops to soil salinity, expressed in terms of soil solution electrical conductivity (ECe) and measured in dS/m, which allows estimation of crop response to salinity:

$$P = 100 - b(ECe - a) \leq 100 \quad (1)$$

Where:

P.- Crop production in % with respect to the maximum.

a.- threshold value of salinity for each crop, below which the crop does not experience a decrease in yields due to salinity.

b.- relationship between P and salinity variations: $b = -\frac{\Delta P}{\Delta ECe}$, where the minus sign indicates that when ECe increases, P decreases.

Applying Maas and Hoffman's formula to the large amount of data collected by Ayers & Westcot (1987), the values of the parameters (a) and (b) for different crops were obtained, these values are given by Pizarro (1985) (Figure 2). It should be noted that for vegetables, during germination and the first phase of the seedling, resistance to salinity is lower than in the following phases; however, the tabulated data refer to the later phases (from growth to maturity). The same author refers to the values of resistance (a) and sensitivity (b) to salinity of vegetable crops.

Agricultural Practices against Salinity

Van Alphen & Ochoa (2004) confirms that the solution of salinity problem is the recovery of affected soils through the application of chemical amendments or the application of leaching techniques. However, there are a series of agricultural practices that help to reduce the harmful effects of salts, which, according to Martínez (2001), can be grouped as follows:

1. Crop selection: According to Maas and Hoffman, crop tolerance to salinity provides criteria for selecting crops that are adapted to each particular condition. In addition to salt resistance, another criterion is the ability to absorb salts from the soil.
2. Improving plant resistance to salinity: These are based on obtaining resistant varieties through artificial selection, intervarietal crossing and hybridization, seed treatment with saline water before sowing and vernalization in nutrient solutions, as well as treatment with growth inhibitors that make plants more resistant to salts.
3. Fertilization: The use of highly soluble salts as fertilizer, especially potassium salts, increases the salt concentration of the soil solution, with correspondingly harmful effects, so less soluble fertilizers should be preferred. Another suitable fertilization measure is the use of organic fertilizers and foliar fertilizers.
4. Irrigation methods and practices: The subirrigation method should be discarded when there are salinity problems. Surface irrigation has the following advantages over sprinkler irrigation in the case of saline soils or water:
   a. It allows more energetic leaching.
   b. The application of saline water on the aerial parts can cause certain damage to them. This is the case, for example, in the sprinkling of citrus fruits with water containing chlorides, which causes burns on the leaves.
   c. Sprinkler irrigation has the advantage of providing the soil with a much more regular distribution of water, surface irrigation can cause soil salinization more easily than sprinkler irrigation, and however, it is more effective in the recovery of already salinized soils.

Soil salinization caused by irrigation depends more on proper water management, in particular excess irrigation water, than on the irrigation technique used.

Irrigation Practices Indicated in the Event of Salinity Problems

1. Irrigate more frequently and at a lower rate than would be the case if there were no salt problems. In this way, the soil moisture does not deviate too far from the field capacity and the salts do not reach an excessive concentration.
2. Small amounts of rainfall are often counterproductive because they wash salts from the soil surface and accumulate in the root zone. For this reason, after a light rain, it is advisable to apply irrigation water to wash the salts accumulated in the root zone.
3. Among the different surface irrigation techniques, furrow irrigation is the one that needs the most careful management in the case of salinity.
4. Localized irrigation allows high frequency irrigation, maintains high levels of humidity in the substrate and reduces the concentration of salts (Vargas, 2003).
5. According to Rodríguez (2006), drip irrigation is not very efficient for the washing of salts; the distribution of salts that occurs has several disadvantages:
   a. In case of rain the salts are introduced in the wet bulb, which is where most of the roots operate. For this reason, it is not advisable to stop irrigation in case of rain, at least in the early stages of crop growth and development.

b. Surface accumulation can affect germination when the roots have not yet reached the wet bulb, especially in horticultural crops, where, when changing crops, seeds can be placed in salinized areas, it is advisable to cause a leaching with rainwater o sprinkler irrigation.

Quality of Irrigation Water

Depeweg & Otero (2004) state that the quality of irrigation water refers to the characteristics of water that may affect the soil-plant complex after long-term use. Sometimes, the farmer uses crops irrigation doses without taking into account the quality of the water. Olías *et al.* (2005) comment that the estimation of the irrigation dose often ignores the fact that the quality of the water may require an extra quantity to guarantee the leaching out of salts. This implies the risk that the continued use of water with a certain saline content may lead to a decrease in crop yields and soil deterioration (Masselink & Short, 1993).

The quality of irrigation water depends on the content and type of salts, the effects of which can be:

1. Salinity: as the salt content in the soil solution increases, the osmotic tension increases, therefore, the plant has to make a greater effort to absorb water and nutrients through the roots.
2. Soil water infiltration: relatively high sodium and low calcium contents cause soil particles to tend to break up, leading to a reduction in the rate of water infiltration, which may imply low water availability in the soil.
3. Toxicity: sodium, chlorine and boron ions can accumulate in crops in concentrations high enough to reduce crop yields and clogging of some irrigation systems.
4. Other effects: sometimes nutrients in irrigation water have to be considered in order to limit fertilization or to avoid excessive corrosion of irrigation equipment, increasing maintenance costs.

The general criteria used to evaluate the suitability of water for agricultural irrigation can be assessed on the basis of the following indicators, Gleick (2003):

Soluble salt contents: Total Soluble Salts (TSS), Electrical Conductivity (EC), Effective Salinity (ES) and Potential Salinity (SP).

1. Probable effect of sodium on the physical characteristics of soils: Sodium Adsorption Ratio (SAR) and Percent Potential Sodium (PSP).
2. Contents of elements toxic to plants, e.g. chlorides, sodium and bicarbonates.

Leaching Programmed with Irrigation Water

Practice has shown that in the case of already desalinated soils where the aim is to avoid re-salinization, the leaching requirements are usually expressed as a percentage of the irrigation water applied, adding an extra amount, so that once the soil reaches field capacity, the excess water percolates to deeper layers. However, although percolation losses have the same effect as leaching water, in most irrigated areas with good drainage; salinity has not increased because salts are flushed out by irrigation losses.

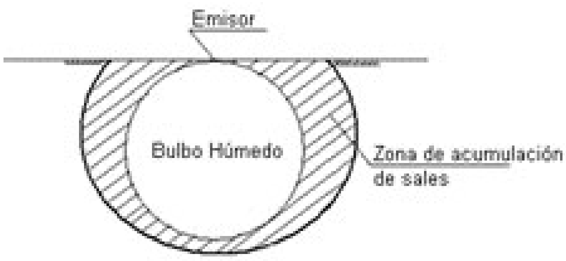

FIGURE 2. Location of salts in drip irrigation (Pizarro, 1985).

The amount of percolation losses depends on soil type, irrigation technique and operator skill, if the leaching requirements are lower than the percolation losses, leaching is assured. However, these losses do not have a uniform distribution. For this reason, it is preferable not to rely entirely on irrigation losses for leaching and to add excess water in the less leached areas.

Leaching of Salts in Localized Irrigation

In localized irrigation systems, the salt regime in the soil is affected by the high frequency and the location of irrigation. In the case of high frequency, its effect is positive, as it allows a favourable irrigation water management for water and nutrient uptake by the crops. After the application of an irrigation, the salts contained in the soil solution, plus those contributed by the irrigation water are dissolved in the soil water, from that moment on, evapotranspiration reduces the soil moisture, but does not eliminate the dissolved salts, and as a consequence, the saline concentration increases until the next irrigation is applied, the higher the frequency of irrigation, the higher the salinity present in the soil solution before the next irrigation.

According to Cruz-Bautista *et al.* (2016), cited by Vargas *et al.* (2021), the effect of dissolved salts is to increase the osmotic pressure and consequently hinder the absorption of water by the roots, a phenomenon that adds to the greater difficulty of absorption due to the decrease in humidity. The high frequency of irrigation facilitates water absorption due to the double effect of maintaining high humidity and low salinity. With regard to the location effect, the distribution of salts in the soil profile is a consequence of the moisture regime; salts accumulate on the periphery of the bulb and especially on the soil surface, and the size depends on the moisture distribution.

The volumes of water applied affect the shape of the bulb and the distribution of salts, the distribution of salts has agronomic consequences: on the one hand, it favours the concentration of roots in the area of higher humidity and lower salinity, but on the periphery of the bulb it establishes a barrier to root development, making it difficult for the roots to explore the part of the soil outside the wet bulb. This makes the system more dependent on irrigation, and light rainfall can be counterproductive by washing away surface salts and introducing them into areas where roots are abundant, which is why irrigation should not be stopped in the presence of light rainfall.

The Role of Tides in Saline Intrusion

According to Edimar-Cuba (2016)), saline intrusion in coastal aquifers can be defined as the increase of salinity in groundwater in contact with the sea caused by human actions, thus being a particular case of groundwater resources pollution. Pérez (2001) states that saltwater intrusion in coastal areas is characterised by the movement of seawater into free or confined aquifers and causes the displacement of freshwater from these aquifers due to overexploitation of the aquifer and tidal oscillation.

The latter author also states that the methods suggested to control saline intrusion include:

- The reduction of extraction
- The redistribution of the location of wells and of the intensity of extraction, without varying the total exploitation
- Direct artificial recharge
- The maintenance of a water barrier above sea level along the coast and the construction of artificial underground barriers.

From the information reviewed, it was found that the water from the supply source used for irrigation is not adequate due to the high concentration of salts caused by the penetration of the salt wedge 1 km inland. Therefore, the solutions must include the improvement of the conditions at the intake site, without reducing the ecological flows of the river towards the mouth. In addition, the programming of recovery and maintenance washes together with the irrigation water that lead to reduce the salinity of the soil and improve the quality of the water for irrigation, so that the appropriate application of organic matter and irrigation water management actions are more effective.

Irrigation Management with Saline Water

As it is well known, the crop does not grow in irrigation water, but in the soil solution, where salts can be much more concentrated. When using water with a relatively high salinity level, the accumulation

Source: Project files of the work.

FIGURE 3. Intake site near the mouth of Miel River, towards Cabacú CC.

of salts in the root zone should be avoided as much as possible and fertirrigation should be managed in such a way as to reduce the absorption of toxic elements. Drip irrigation is best suited for use with saline water due to its characteristics. Drip irrigation allows a moisture content in the root zone close to the field capacity to be maintained, which prevents a high concentration of salts. This means that the wet bulb area occupied by the roots is frequently moistened, which prevents the accumulation of salts, and the leaves are not wetted by the irrigation water.

When drip irrigation is used, the plant's root system is smaller and there is constant leaching, so fertilisation is necessary all the time to avoid deficiencies and imbalances. It should also be consider that there is a risk when it starts to rain, because if it does not rain enough to displace the salts below the root zone, the rainwater can introduce the salts accumulated into the root zone, especially in semi-protected crops.

MATERIALS AND METHODS

Description of the Study Case

The UEB Casa de Cultivo is located in Cabacú, in Baracoa City, Guantánamo Province and belongs to the Empresa Agroforestal and Coco. It is bordered to the north by cattle grazing areas, to the east by a Day Care Centre and the “Salvador Pascual” Primary School, to the south by private houses and the Farm “13 de Agosto”, and to the west by a brick factory and a group of private houses. Its social purpose is to ensure the entire process of production of vegetables for the surrounding population and tourism.

The installation is composed of 24 greenhouses and two irrigation systems, one with the low-pressure conventional sprinkler for the benefit of crops in the open parcel and another with drip irrigation for the greenhouses. The main crops are cucumber, tomato, melon, lettuce, cabbage and spinach (the last three are sprinkler irrigated).

It is made up of 30 modules of Protected Crop Houses, of which 16 have dimensions of 20 x 40 m and 14 have dimensions of 12 x 15 m. It also has a 12 x 15 m Nursery House and a 1ha of Semi-Protected Organoponics Unit, both irrigated with a localized micro-sprinkler irrigation system. It also foresees the installation of a vermiculture area, a substrate preparation shed, and a processing centre for the semi-protected area.

Agronomic Parameters

For the Greenhouses:

The emitter used was the TWIN DRIP integrated in LDPE pipe of 15.50 × 13, 50 mm, which discharge a flow rate of 2.00 L/h with a working pressure of 98.04 kPa and 2.45 L/h with 147.06 kPa, respectively. The manufacturing coefficient of variation (C_{VF}) is 0.3% which places it in category A of the international ISO standard. The spacing between emitters is 0.40 metres and the spacing between laterals is 1.0 m, for an average hourly application intensity of 5.00 mm/h for the 2.0 L/h drippers and 6.12 mm/h for the 2.45 L/h drippers.

Peak water requirements were estimated at 3.5 mm/day, which led to irrigation between 0.67 and 0.82 hours in each case, with a daily frequency in both cases. The maximum time available for daily irrigation was 8.0 hours, distributed in 12 irrigation shifts for the 20 × 40 m block and 7 irrigation shifts for the 12 × 45 m block (in the latter the maximum operation time decreases to 5.74 hours).

For the Nursery Houses:

A domestically produced "C" series 2x140° micro-sprinkler set with nozzle diameter 1.0 mm was used which delivers a flow rate of 40.65 L/h with a working pressure of 147.06 kPa, these emitters are over line spaced 1 m along the lateral pipes. The spacing between laterals is 2 m, with each one located on each row (6 in total). The application intensity obtained with this spacing is 20.32 mm/hr. A peak water requirement of 5.0 mm/day was estimated, the guarantee of this dose considering the application intensity of 20.32 mm/h and a daily irrigation interval is obtained with 0.28 h timing application.

For the Semi-Protected Organoponics Unit:

The same micro-sprinkler set was used, the peak water requirement resulted in 4.0 mm/h, with the application intensity of 20.32 mm/h and daily irrigation interval, the application time was 0.23 h and the time available for daily irrigation was 8.0 h. It was considered appropriate to subdivide the total area into 24 shifts, which resulted in a maximum actual operating time of 5.52 h.

Data on the Source of Supply

Miel River located in the southwest of Baracoa Municipality was used, it has a total length of 30.6 km and the coordinates of the mouth are located at N 189.000 and E 745.400 at 200 m from the irrigation areas. The quality of the water in the installation is not adequate for irrigation, the intake work is in the open air and unprotected, as shown in photo 2. The analyses were carried out at CNEA Laboratory in Oriente University, which has international certification for quality standards.

Sampling was carried out according to the NC-93-02 (1985) and for two moments linked to the wet and dry periods. The results of the different water quality indicators were compared with the irrigation water classifications proposed by Ayers & Westcot (1987), the Scott index and the Riverside Standards. Samples were taken from two different sources, one from the well where the pumping station is located and the other from the Miel River. The samples taken from the sources correspond to low tide and high tide. The results obtained refer to the following indicators: dissolved oxygen, electrical conductivity, pH, salinity and total dissolved salts. Sampling was not carried out during the operation of the well.

When comparing the different quality indicators evaluated with the optimum values proposed by other authors, it was found that the average pH in all samples was 7.86 ±0.25, with a minimum of 7.66 (±0.02) and a maximum of 8.29 (±0.06), only resulting slightly alkaline (pH <8) in one of the samples, mainly at low tide. The reported values are within the range (6-8.5) established by different water quality criteria.

The average electrical conductivity (EC) is 0.514 ±0.04, with a minimum of 0.275 (±0.02) dS/m and a maximum of 0.756 (±0.01) dS/m. The reported values are within the range (0-3). Samples taken from the river had the lowest values (0.275-0.290), samples from the well were twice as high as these values. The maximum values of the river and the well were taken at high tide. It was observed that the (EC) of the samples in the same source increases with the oscillation of the tide, also inside the well the values are higher because the depletion cone approaches the wedge of saline intrusion as it happens in the coastal aquifers due to an excessive exploitation (Pérez, 2001).

Design Parameters of the Irrigation System

Climate Data

It is characterised by the influence of the trade winds from the north-east during the months of May to October and from the east and south-east during the months of November to April, associated with the

TABLE 1. Design parameters of the irrigation system

Design data	CR2	CR1	Organoponics
Crop	Vegetables	Vegetables	Vegetables
Net area to be irrigated (ha.)	1,28	0,81	1,0
Planting frame (m × m)	Beds	Beds	Beds
Water source	Surface	Surface	Surface
Irrigation technique	Localised	Localised	Localised
Emitter type	Twin Drip	Twin Drip	Microjet
Emitter flow rate (L/h)	2,45	2,00	40,65
Working pressure (kPa)	15,00	10,13	15,00
Emitter spacing (m)	0,40	0,40	1,00
Lateral pipe spacing (m)	1,00	1,00	2,00
Application rate (mm/h)	6,12	5,00	20,33
Total requirements (mm/d)	3,5	3,5	4,0
Irrigation frequency (d)	1,17	1,17	1,17
Application timing (h)	0,67	0,82	0,23
Irrigation deep (mm)	4,10	4,10	4,68
Shifts per irrigation cycle (u)	12	7	24
Daily operating time (h)	8,00	3,74	8,00
Maximum flow rate per shift (L/s)	1,36	1,5	2,16
Minimum flow rate per shift (L/s)	2,72	1,5	2,168
Head inlet load (kPa)	28,69	19,92	28,44

activity of anticyclones from the North Atlantic and the relief of the area, which form orographic barriers. The mean annual temperature is 25.8 ^{O}C with mean monthly values between 23.7 ^{O}C in January and 27.7 ^{O}C in July and August. Average rainfall 1683.3 mm/year, with the lowest average months registering more than 90.0 mm and the wettest above 250.0 mm. There is no significant seasonal difference, the climate in this zone is classified as tropical rainforest and annual relative humidity is 82%.

Crop Characteristics

Cucumber, tomato, pepper and melon.

Sowing frame: 0.15 x 0.15 cm.

Root depth: 80 cm.

Crop height: 80 cm.

Minimum relative humidity = 70 % and maximum = 80 %.

Despite repeated changes of substrate, the salt content has still not been reduced, and the poor quality of the irrigation water persists. Sowing in nylon bags and planting in beds with organic matter have not led to the desired yields either. Analyses indicate the need to improve the cistern and to schedule recovery and maintenance leaching of the soils, as well as to use irrigation water in accordance with the tidal oscillation and to maintain the application of organic matter.

The levels of salinization in the semi-protected cultivation were lower than in the greenhouses, due to the influence of rain, which generally has a neutral pH and decreases the levels of salts in the substrate, favouring an increase in yields. In the greenhouses, the content of salts in the substrate increased when irrigation was carried out, demonstrating the relevance of rehabilitating the cistern.

Tidal Oscillation

Tidal movement takes place 24 hours a day, 6 hours up, 6 hours high and 6 hours down, 6 hours low. The seawater wedge penetrates 1km upstream of the river, increases the salinity of the river and contaminates the underground source of the well that feeds the irrigation areas. The salt wedge is linked to the movement of the tide, increasing the salinity and affecting mainly cucumber, tomato and pepper crops. This situation was aggravated by the quality of the water that was being used, the pH of which ranged between 8.5 and 9. In measured observations, the pH of the water obtained values of pH = 10, which favoured the emergence of the culm in the tomato, the curving of the leaves and the maintenance of the green colour. At pH = 9, leaf scorch was observed in the apical buds (upper part of the tomato stem). When pH = 8.8, recovery was noted.

Programming of the Recovery Leaching

Data:

Initial salinity of substrate ECe = 6 dS/m

Substrate porosity ϵ = 31 %.

Field Capacity Cc = 47 %V

Wilting point Pm = 18 %V

Leaching efficiency f = 0,5

Root depth Prad. = 200 mm

Irrigation is planned when 1/3 of the usable water has been consumed

No capillary inputs are considered (G = 0).

Frequency of application = 10 d

Evaporation for 10%p = 7.58 mm/day

No rainfall inputs between irrigations are considered (P = 0)

Salinity of irrigation water ECi = 0.6 dS/m

An initial vigorous leaching is foreseen to recover the quality of the substrate and to lower the initial salinity to values that can be sustained by maintenance leaching with irrigation water. The irrigation water should replenish the evapotranspiration demand for 10 days (7.58 10 = 75.8 mm), and it is initially assumed that the leaching water (R) = 20 % of the irrigation water (I). The salt balance equation was applied in the root zone to estimate the magnitude of the leaching water (R):

$$I + P = E + R \quad (2)$$

To programme the recovery leaching, the following is used:

$$\Delta Z = \frac{(\mathrm{A} - \mathrm{B} \times \mathrm{Z}_1)}{(1 + 0{,}5\mathrm{B})} \quad (3)$$

Where:

ΔZ.- Variation of salt content in the substrate (ECmm).

Z_1.- Initial content of salts in the substrate (ECmm).

$$A = CE_i(I - R + Rf) \quad (4)$$

$$B = \frac{R^*f}{Hc} \quad (5)$$

Hc.- Moisture content in the substrate at field capacity (mm).

$$Z_1 = Hc \times C_{cc1} \quad (6)$$

$$Ccc_1 = \frac{(CEe_1 \times \epsilon)}{Cc} \quad (7)$$

Z2 being the final content of salts in the substrate, after applying the recovery leaching. Its value is cleared from:

$$\Delta Z = Z_1 - Z_2 \quad (8)$$

Thus, the salinity of the substrate when it is in field capacity conditions (Ccc2), is obtained by:

$$C_{cc2} = \frac{Z_2}{Hc} \quad (9)$$

And the final salinity in the substrate would be:

$$CEe_2 = C_{cc2} \times \left(\frac{Cc}{\epsilon}\right) \quad (10)$$

Programming of the Maintenance Leaching

It is planned to programme a maintenance leaching to maintain the substrate salinity at the end of each season at values that can be tolerated by the projected crops. The following equation was used to estimate the magnitude of the leaching water (R):

$$R = \frac{(E - P)CE_i}{f(C_{cc} - CE_i)} \quad (11)$$

In which the values of (E), (P), (CEi) and (f) are maintained, (Ce_2) and (Ccc_2) are obtained from Table 2 for the 9th leaching. From the rinsing water (R) and using (2) it is possible to obtain the magnitude of the irrigation dose and to check if there is a balance between the quantities of salts supplied by irrigation and those eliminated during rinsing, as follows:

$$I \times C_i = R \times C_R \quad (12)$$

Where the salinity of the leaching water is estimated by:

$$C_R = f \times C_{cc} + (1 - f)CE_i \quad (13)$$

RESULTS AND DISCUSSION

In Table 2, the results of the recovery leaching programming are shown.

The initial salinity CEe_1 = 6 dS/m, is reduced to CEe_2 = 3.20 dS/m, after the ninth leaching. In order to recover the quality of the substrate, it was suggested to use a portable sprinkler irrigation system, pg. The 2 nozzle sprinkler VIII, which delivers a flow rate of 6.86 m3 /h, at a pressure of 3.8 - 5 Kg/cm2 and a radius of 20.5 m, can be used, as it cannot be applied with the drip irrigation system. Initially, the electrical conductivity in the substrate CEe_1 = 6 dS/m was only tolerable by the cultivation of melons and it was not possible to plant peppers, tomatoes and cucumbers. The latter is the most sensitive of the four and requires an ECe value ≤ 3.23 dS/m to guarantee 90% yield. The solution entails lowering the salinity of the substrate to 3.20 dS/m, in order to irrigate the melon,

TABLE 2. Result of the recovery leaching programming

Programming	Ce_1 (dS/m)	I(mm)	R(mm)	Ccc_1 (dS/m)	Z_1 (CEmm)	ΔZ (CEmm)	Z_2 (CEmm)	Ccc_2 (dS/m)	Ce_2 (dS/m)
1st leaching	6.00	94.75	18.95	3.96	372	13.01	358.99	3.82	5.79
2nd leaching	5.79	94.75	18.95	3.82	358.98	14.26	344.72	3.67	5.56
3rd leaching	5.56	94.75	18.95	3.67	344.72	15.63	329.09	3.50	5.31
4th leaching	5.31	94.75	18.95	3.50	329.22	17.12	312.10	3.32	5.03
5th leaching	5.03	94.75	18.95	3.32	311.86	18.78	293.08	3.12	4.73
6th leaching	4.73	94.75	18.95	3.12	293.26	20.57	272.69	2.90	4.40
7th leaching	4.40	94.75	18.95	2.90	272.80	22.53	250.27	2.66	4.04
8th leaching	4.04	94.75	18.95	2.66	250.48	24.67	225.81	2.40	3.64
9th leaching	3.64	94.75	18.95	2.40	225.68	27.05	198.63	2.11	3.20

tomato, pepper and cucumber crops. Subsequently, in order to maintain this value, leaching doses will be applied with irrigation.

In Table 3, the results of the maintenance-leaching programming are shown.

As it can be seen, ICi and RCr coincide, after recovering the soil, it is necessary to plan maintenance leaching, which will be done using the salt balance equations. This is achieved by applying at each irrigation a leaching dose equivalent to 44% of the irrigation dose. Considering a daily evaporation of 10 %P = 7.58 mm/d and the available value of the rainfall input is 0 (because of being a covered farmhouse or greenhouse), the annual irrigation rainfall would be = 2766.7 mm in correspondence with its substrate salinity at field capacity Ccc = 8.15 dS/m. The salts contributed in the irrigation season resulted ICi = 8.15 CEmm. Therefore, the salts eliminated by the drainage substrate RCr = 8.15 EC mm, these values must coincide as a guarantee that the soil salinity (ECe) will not increase to values harmful to the most sensitive crops.

Irrigation Management with Saline Water

To avoid the negative effects of salinity in the medium and short term and to guarantee the proper functioning of the irrigation system, it was proposed to restructure the supply system of the Organoponics, disconnecting the pumping station from the well, building a regulating tank to store the water from a new intake on the banks of the Miel River. It has a protection with a grid chamber connected to a pipe and a valve to control the flow that reaches the suction chamber for the pump.

The regulating tank should store the necessary amount of water for the washing and recovery of the soil, as well as for its later maintenance, also contributing to the agricultural irrigation in the different cultivation houses during high tide. It can be built with local material from the excavation and waterproofed with clay. For the saline soil recovery leaching, a 200 mm water level is needed; this represents 33.2 L/s/ha, as the cultivation houses occupy a surface of 2.1 ha, this requires a flow equal to 70 L/s, with this value the volume of the reservoir can be obtained. The volume of water for the leaching is 200mm, equivalent to 200 L/m^2; therefore, for an area of 2.1 ha, 4200m^3 are needed. These washes should be done before the sowing work, the maximum volume of the regulating tank is 4 400m^3.

In the study area, before sowing the crop, it is necessary to leach the substrate to recover it, this requires a volume of 4 200m^3. Knowing that the quality of water for irrigation is better at low tide, only 12 hours a day are available for pumping, but for operational reasons and for the protection of the equipment, only 8 hours will be pumped.

The existing pump delivers a maximum flow of 8 L/s, which means that in 4 hours of pumping only a volume of water of 172 m^3 and 345 m^3/d can be obtained. With this last value, the soil leaching time of 2.1ha of crop takes 12 days. This action is recommended to be applied using portable sprinkler irrigation, with a sprinkler with two nozzles, which delivers a flow of 6.86 m^3/h, working pressure = 3.85 kg/cm^2 and a radius of reach = 20.4 m. With drip irrigation, 6 mm of water needs to be applied to ensure the necessary water for the crop and soil maintenance, which implies that in the 2.1 ha of cultivation, a daily water volume of 126 m^3 is required. This volume can be supplied by the pumping station in less than 4 hours.

CONCLUSIONS

- It was found that water quality deteriorates with increasing tides, which is more evident in the well, and a procedure for leaching the substrate considering the lunar phases was established: recovery washes and maintenance washes applied with irrigation water.
- The dose for the recovery leaching was estimated at 200 mm, the dose for the maintenance leaching was estimated at 17 % of the irrigation dose, for which 6 mm/d was considered.
- To maintain CEe ≤ 3,23 dS/m favourable to the cucumber crop, the time of application will be increased up to 2.2h: 2.7h; 0,7h in the parcels CR2; CR1 and in the Organoponic, respectively.
- It was established as a strategy to restructure the supply system of the Organoponics, disconnecting the pumping station from the well and building a regulating tank to store the water from a new intake work on the banks of the Miel River. That intake work has protection with a grid chamber connected with a pipe and a valve to control the flow that reaches the suction chamber for the pump.

REFERENCES

AYERS, R.S.; WESTCOT, D.W.: *Water quality for agriculture*, Ed. Food and Agriculture Organization of the United Nations Rome, vol. 29, Rome. Italy, Estudio FAO. Riego y Drenaje.No.29, Rev.21, 1987, ISBN: 92-5-102263-1.

TABLE 3. Results of the maintenance-leaching programming

R (mm)	I (mm)	R/I(%)	C_R(dS/m)	RC_R(CEmm)	IC_i(CEmm)	Ccc (dS/m)	Ce (dS/m)
6	13.58	44	1.36	8.15	8.15	2.12	3.21

CRUZ-BAUTISTA, F.; ZERMEÑO-GONZÁLEZ, A.; ÁLVAREZ-REYNA, V.; CANO-RÍOS, P.; RIVERA-GONZÁLEZ, M.; SILLER-GONZÁLEZ, M.: "Validación de un modelo para estimar la extensión del bulbo de humedecimiento del suelo con riego por goteo", *Tecnología y ciencias del agua*, 7(1): 45-55, 2016, ISSN: 2007-2422.

DEPEWEG, H.; OTERO, F.M.: "Optimization of water management in the RUT Irrigation District, Colombia", *Irrigation and drainage*, 53(1): 55-67, 2004, ISSN: 1531-0353.

EDIMAR-CUBA: *Tablas de Marea de las Costas de Cuba.*, Ed. Agencia de cartografía Náutica GEOCUBA Estudios Marinos, Servicio Hidrográfico y Geodésico de la República de Cuba ed., Punta Santa Catalina, Regla, La Habana, Cuba, 2016.

GLEICK, P.: "Water use", *Annual Review of Environment and Resources*, (28): 275-314, 2003.

MARTÍNEZ, B.J.: *Control de la salinización de suelos regables*, Centro de Estudios Hidrográficos CEDEX. Centro de Experimentación de Obras Públicas, Master en Ingeniería de Regadíos, Madrid, España, 2001.

MASSELINK, G.; SHORT, A.D.: "The effect of tide range on beach morphodynamics and morphology: a conceptual beach model", *Journal of Coastal Research*, 9(3): 785-800, 1993, ISSN: 0749-0208.

MATOS, R.M.: *Propuesta para el manejo del riego con aguas de salinidad media en la UEB Cultivo Protegido Cabacú*, Universidad de Oriente, Tesis de Grado. Especialidad Ingeniería Hidráulica, Santiago de Cuba, Cuba, 2017.

OLÍAS, M.; CERÓN, J.; FERNÁNDEZ, I.: "Sobre la utilización de la clasificación de las aguas de riego del US Laboratory Salinity (USLS)", *Geogaceta*, 37(3): 111-113, 2005.

PÉREZ, D.: *La explotación del agua subterránea. Un nuevo enfoque*, Ed. Editorial Félix Varela, La Habana, Cuba, 322 p., publisher: La Habana: Editorial Félix Varela, 2001.

PIZARRO, C.F.: *Drenaje agrícola y recuperación de suelos salinos*, Ed. Editorial Agrícola Española, S.A, 2a ed., Madrid, España, 541 p., publisher: Madrid (Spain) Edit. Agricola Espanola, 1985.

PIZARRO, C.F.: *Sistemas de riego localizado de alta frecuencia (Goteo, Micro aspersión y Exudación)*, Ed. Mundiprensa, 2da ed., Madrid, España, 1996.

RITZEMA, H.P.: "Subsurface flow to drains", *Drainage principles and applications*, 16: 263-304, 1994.

RODRÍGUEZ, M.R.: *Riego localizado de alta frecuencia*, Inst. Instituto de Investigación de Riego y Drenaje, Departamento de Riego, Informe técnico, La Habana, Cuba, Convenio Bilateral Cuba-Venezuela, 2006.

VAN ALPHEN, G.P.: "Rice in the reclamation of salt-affected soils", En: Bangkok, Tailandia, 1983.

VAN ALPHEN, J.G.; OCHOA, M.P.: *Perfeccionamiento del sistema de drenaje en la zona Fidelina-Guamá*, Inst. Estación de Investigaciones de Café y Cacao, Departamento de Riego y Drenaje, Informe técnico, Baracoa, Guantánamo, Cuba, 2004.

VAN HOORN, J.W.: "Effect of capillary flow on salinization and the concept of critical depth for determining drain depth", En: Ed. Wageningen, International Institute for Land Reclamation and Improvement, 1979., pp. 686-700, 1979.

VAN HOORN, J.W.: "Salt movement, leaching efficiency, and leaching requirement", *Agricultural Water Management*, 4(4): 409-428, 1981, ISSN: 0378-3774.

VARGAS, R.P.: *Aspectos básicos y elementos para el diseño de sistemas de riego localizado. Goteo y microaspersión*, Inst. Universidad de Oriente, Facultad de Construcciones, Departamento de Ingeniería Hidráulica, Informe técnico, Santiago de Cuba, Cuba, 2003.

VARGAS, R.P.; DORTA, A.A.; BARILLAS, K.E.; MÉNDEZ, J.A.A.: "Consideraciones para el diseño racional de sistemas de riego por goteo", *Revista Ciencias Técnicas Agropecuarias*, 30(4), 2021, ISSN: 2071-0054.

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