ORIGINAL ARTICLE

Irrigation Management to Reduce Negative Environmental Impacts

La gestión del riego para la reducción de impactos negativos ambientales

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ABSTRACT: Historically, efforts to improve efficiency in the use of water and energy have been carried out separately. Güira de Melena Municipality is located on an underground aquifer open to the sea where the phenomenon of saline intrusion is present. That is why the work aims to show the importance of irrigation programming in water and energy consumption as a measure to mitigate environmental damage. For the study, different farms that planted potatoes under electric central pivot machines were evaluated, where irrigation was carried out using the "Irrigation Forecast" tool. In addition, the influence of said forecast on energy consumption was evaluated following the Energy Audit protocol, all of which was compared with the irrigation management carried out by the Municipal Agricultural Company. The results revealed that irrigation programming through the tool in the evaluated entities was effective in reducing the volumes of water consumed by 23% on average and energy by 8.8% with respect to the current consumption of the company, which emphasizes the need for proper irrigation management as an action to reduce environmental damage.

Keywords: Irrigation Forecast, Central Pivot, Energy Efficiency.

RESUMEN: Históricamente, los esfuerzos para mejorar la eficiencia en el uso del agua y la energía han sido llevados a cabo por separado. El municipio Güira de Melena se encuentra sobre un acuífero subterráneo abierto al mar donde el fenómeno de intrusión salina está presente. Es por ello que el trabajo tiene como objetivo mostrar la importancia de la programación del riego en los consumos de agua y energía como medida para mitigar los daños ambientales. Para estudio fueron evaluadas diferentes fincas que sembraron papa en máquinas de pivote central eléctricas, donde el riego se ejecutó utilizando la herramienta *"Pronóstico de riego"*. Además se evaluó la influencia de dicho pronóstico en los consumos energético siguiendo el protocolo de Auditorías Energéticas, todo ello se comparó con el manejo del riego efectuado por la Empresa Agropecuaria del municipio. Los resultados revelaron que la programación del riego a través de la herramienta en las entidades evaluadas fue efectiva al reducir los volúmenes de agua consumidos en un 23% como promedio y la energía en 8,8% con respecto a los consumos actuales de la empresa, lo que enfatiza la necesidad de la adecuada gestión del riego como acción para la reducción de los daños ambientales.

Palabras clave: pronóstico de riego, pivote central, eficiencia energética.

INTRODUCTION

Increasing the efficiency of the use of water and energy in agriculture is of vital importance in the face of climate change (Selim et al., 2018), so it is necessary to generate adaptation actions that allow the planning, operation and evaluation processes of the irrigation service to be adapted (Ojeda et al., 2012).

According to EFEAGRO (2012), countries have committed to meeting the Sustainable Development Goals (SDGs), one of which (number 6) seeks to guarantee universal access to safe and affordable drinking water for all by 2030. To achieve this, the efficient use of water resources must be increased in all sectors, including agriculture, which represents 69% of the world's freshwater consumption. It also highlights the importance of maximizing water productivity, since it is necessary to increase food production through more efficient water use. It is also about avoiding "environmental degradation", since in many places aquifers are being depleted, the flow of rivers is decreasing and pollution from cities is increasing.

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One of the ways to achieve an adequate use of water and energy is through irrigation programming. Irrigation scheduling refers to how much, when and how to irrigate crops to obtain maximum water efficiency and productivity (Trezza et al. 2008).

Güira de Melena Municipality is located on an underground aquifer open to the sea where the phenomenon of saline intrusion is present, it has a large part of its agricultural area under irrigation infrastructure, with about 40,000 hectares dedicated mainly to root crops, vegetable and grains. With a total area under irrigation of 5,600.27 hectares, 5,539.22 ha have use value. At the end of 2019, the Irrigation and Mechanization Establishment reports that there are 5,328.15 hectares under irrigation in exploitation, of them, electric central pivot machines represent 25% with more than 15 years of exploitation. There, the quality parameters of irrigation have been recently deteriorated, affecting the standards of delivery to crops and the levels of water extraction from the aquifer (Cisneros et al., 2021).

That is why this paper aims to show the importance of irrigation programming in water and energy consumption as a measure to mitigate environmental damage**.**

MATERIALS AND METHODS

The work was carried out at Güira de Melena Agricultural Company in Artemisa Province, with geographic coordinates 22° 44' 6.39", north latitude and 82° 30' 11.54" west longitude. The height above mean sea level is 8 m. Figure 1 shows the geographical location of the municipality.

For the work, different productive forms were selected like Basic Unit of Cooperative Production (UBPC) and Cooperative of Agricultural Production (CPA) within the Agricultural Company, which planted potatoes with very similar planting dates during the campaign and irrigated them with electric central pivot machines.

Irrigation programming was carried out in 37% of the total area planted by the company, which was 340 hectares of the aforementioned crop.

The predominant soil in the study areas, according to the second genetic classification of Cuban soils (Instituto de Suelos, 1980), is of compacted Ferralitic Red type that corresponds to a hydrated compacted Ferralitic Red, according to Hernández et al. (2003), cited by Cid et al., 2012).

Irrigation programming was carried out using the tool "Irrigation Forecast Sheet" defined by Cisneros et al. (2007). This tool has been used and validated by authors such as Aguilar (2012), Maza (2018) and recently, by Matos et al. (2020). It is based on a simplified algorithm of water balance of the soil moisture defined by López (2002).

FIGURE 1. Geographic location of Güira de Melena Municipality in Artemisa Province.

Irrigation programming with the use of the tool referred was compared with that applied by Güira de Melena Agricultural Company during the campaign studied. The number of irrigations was between 20 and 21, the average net partial standard was 280.0 m^3 •ha^{-1}, irrigation interval every four days, with an average yield of 22.8 t.ha^{-1} according to Sánchez (2020), head of irrigation at Güira de Melena Agricultural Company, (personal communication and final irrigation report campaign).

For the study of energy efficiency, the Energy Audit protocol published by the Institute for Energy Diversification and Saving (IDEA) (Abadía et al., 2008) was used, which contemplates a series of energy use indicators utilized to energetically evaluate irrigation communities. A qualification is proposed based on the General Energy Efficiency (EEG) and the active energy consumed per hectare (Eaa).

The EEG is obtained as the product of the Energy Efficiency of Pumping (EEB) and the Energy Supply Efficiency (ESE). The EEB represents the joint performance of the pumping group, while the ESE represents the relationship between the energy demanded by the irrigation system and the energy supplied. The rating given in the Energy Audit Protocol establishes 5 groups based on the EEG value, as it can be seen in Table 1.

Regarding the consumption of active energy per unit of irrigated area (Eaa), 5 groups are also established as shown in Table 2.

In addition to these indicators, among those proposed in the Protocol, there are two that provide very specific information on how energy is managed in the Irrigation Community. They are the active energy consumed per volume unit (Eav), also called specific energy consumption, measured in kWh•m^{-3} and the energy cost per volume unit (Cev), also called specific energy cost measured in $•$m^{-3.}$ The first of them gives an idea of the energy consumption that supposes each m^3 of water utilized in the studied entity. On the other hand, the second indicator gives an idea of the economic efficiency of electricity tariff management. These two indicators are disaggregated from the supply of water that the productive unit has and its higher or lower value is indicative of a higher or lower energy consumption and cost.

RESULTS AND DISCUSSION

Influence of Irrigation Scheduling on Water Consumption and Crop Yield

Table 3 shows the average behavior of irrigation in the entities studied during the campaign and that executed by the company. For programmed irrigation, the irrigation number was 18.71 and the irrigation interval (IR) was 3.37 days depending on the planting dates and the evaporative demand of the atmosphere. For the company, 21 were applied with an irrigation interval of 4 days. In the same table, it is also observed that the average partial net norm (NNP) was 240.6 m^3•ha^{-1} for the irrigation programmed and 280.0 m^3•ha^{-1} for the irrigation carried out by the company.

Similar results were obtained by Maza (2019) and Cisneros et al. (2020), managing irrigation according to the water needs of the crop in the same study area.

The average yield in the agricultural company was 22.8 t•ha^{-1} while for the farms studied it was 29.7 t•ha^{-1}, resulting in a 30% higher. In a general sense, the number and interval of irrigation, partial and total net norm for the average of all the areas under irrigation forecast with respect to the average of the rest of the areas of the agricultural enterprise are lower, thus confirming the effectiveness of this irrigation management procedure to achieve an efficient use of water and energy and the reduction of environmental damage.

Impact of Irrigation Management on Water and Energy Consumption

Properly managing irrigation allows significant reductions in the volumes of water to be extracted from the aquifer and consequently protection of such an important and finite natural resource. As it can be seen in Figure 2, by scheduling irrigation, only 29,935.45 m^3 are needed to satisfy the irrigation needs of potatoes, while 60,362.40 m^3 are necessary to achieve the same purpose in the company.

By transferring irrigation to all areas of the company, as was done in the entities studied, the total net standard could be reduced by 23% and with it the extraction of the aquifer. Similar reductions were obtained by Aguilar (2012) with the programming of the irrigation in identical crop and study area.

In energy terms, from 23 to 48% of the energy used directly for agricultural production is for pumping water on farms (Singh et al., 2002).

Figure 2 shows the behavior of this relationship in the evaluated sites, where the average energy consumption among all the farms was 24.15 mW, while in the company it reached the value of 48.72 mW, in this sense of having Once the irrigation programming has been executed throughout the company, energy consumption is reduced by 8.8% with respect to current consumption in said productive entity.

TABLE 1. Energy rating of an Irrigation Community

RATING DESCRIPTION	DESCRIPTION	SPECIFICATIONS
A	Excellent efficiency	EEG ≥ 50%
B	Good efficiency	40% ≤ EEG < 50%
C	Standard efficiency	30% ≤ EEG < 40%
D	Acceptable efficiency	25% ≤ EEG < 30%
E	Not acceptable efficiency	EEG < 25%

TABLE 2. Rating based on active energy consumption per irrigated hectare

Group	Description	Specifications
1	Non-consumer	Eaa = 0
2	Little consumer	0 < Eaa ≤ 300
3	Average consumer	300 < Eaa ≤ 600
4	Consumer	600 < Eaa ≤ 1000
5	Big consumer	Eaa > 1000

Eaa: Active energy consumed per irrigated hectare (kW.ha^{-1}.$year^{-1}$)

TABLE 3. Results of the irrigation campaign. Average values

Farm	Area (ha)	No. Of irrigation	I R (days)	NNP (m^3·ha^{-1})	NNT (m^3·ha^{-1})	Yield (t·ha^{-1})
Programming	124.42	18.71	3.37	240.64	4502.43	29.70
Company	340.00	21.00	4.00	280.00	5880.00	22,80

When proposing energy saving and efficiency measures according to the Institute for Energy Diversification and Saving (IDAE, 2008), special attention must be paid to the critical points of energy consumption of irrigation communities.

Table 4 shows the general characteristics of the systems studied and the highest hydro module of 1.58 $L \cdot s^{-1} \cdot ha^{-1}$ as an average among the company's farms, that presents the largest surface area irrigated and the largest volume of billed water.

Table 5 shows the value of the indicators analyzed. The general energy efficiency (EEG) and energy consumed per unit of irrigated area (Eaa) are not totally consistent according to Moreno et al. (2009b) and their use to analyze the evolution in successive campaigns of energy consumption in productive entities, as well as to compare different irrigation communities with each other, can lead to interpretation errors.

Regarding the EEG, according to the criteria of Table 1, the entities where the irrigation was programmed are classified as of acceptable efficiency, while the entities where the irrigation was carried out with norms and fixed intervals (company) are classified with non-acceptable efficiency.

Moreno et al. (2009a) state that another indicator used in the ratings is the energy consumed per unit of irrigated area (Eaa) and its value is linked to the consumption of water in the irrigable area. It can adopt very high or very low values, because of an excess or deficiency of availability of irrigation water.

Figure 3 shows the values of active energy consumed per hectare (Eaa) in the potato campaign against the consumption thresholds set in Table 2. As observed in the joint analysis of all the farms where irrigation was managed through the forecast sheet (Prog.), they are in the range of moderately consuming to consuming. The farms in Güira de Melena Agricultural Company, where irrigation management was not carried out taking into account the evaporative demand of the atmosphere, are classified as consumer and large consumer according to the classification of Table 2, energy audit protocol.

From the study, it was possible to know the importance of energy analysis in the irrigation activity

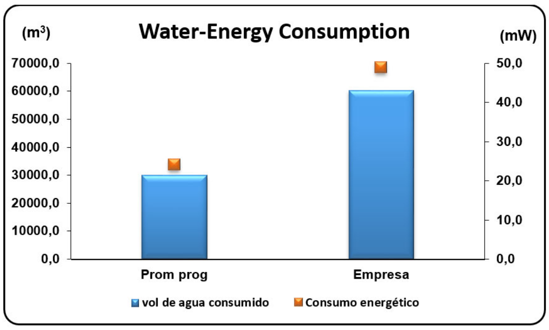

FIGURE 2. Water and energy consumption between scheduled irrigation and that carried out by Guira de Melena Agricultural Company.

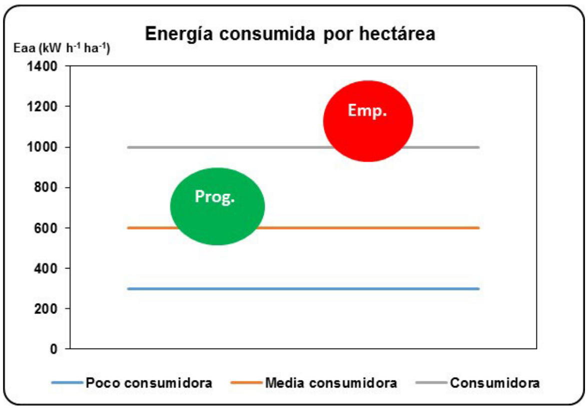

FIGURA 3. Active energy consumed per hectare watered in the farms studied.

TABLE 4. General characteristics of the systems studied

Entities	Hydro module ($L\ s^{-1} \cdot ha^{-1}$)	Surface watered *(ha)*	Volume of billed water *(H·m³)*	IDE* *(%)*	Hydraulic Sectors	Type of supply
Programming	1.33	124.42	0.560	100	1	MPC
Company	1.58	340.00	1.999	100	1	MPC

*IDE represents the relationship between the volume of water pumped and the total volume of water supplied. MPC Electric Center Pivot Machine.

TABLE 5. Value of the indicators analyzed

Entities	Eaa ($kWh \cdot ha^{-1}$)	Eav ($kWh \cdot m^{-3}$)	Cea ($\$ \cdot ha^{-1}$)	Cev ($\$ \cdot m^{-3}$)	ICE (m)	EEB (%)	ESE (%)	EEG (%)
Programming	787.91	3.283	229.07	0.952	19.3	58.30	46.48	27.10
Company	1199.86	4.290	347.96	1.244	33.8	52.69	44.22	23.30

Legend: Eaa: Energy consumed per unit of irrigated area; Eav: Specific energy; Cea: Energy cost per irrigated area; Cev: Energy cost per m^3 supplied to irrigators; ICE: Energy charge index; EEB: Energy efficiency of pumping; ESE: Energy supply efficiency; EEG: General energy efficiency.

in order to minimize production costs. In addition, as it can be seen in Table 4, the hydromodule has a great weight within it, where it is considered that, as average in the company, the hydromodule is of 1.58 L•s^{-1}•ha^{-1}, an element to take into account in the pump-motor-area relationship and not unnecessarily oversize the pumping equipment. Results obtained by González and Cisneros (2003) when carrying out a study of the selection of pumping equipment in Batabanó Various Crops Company, concluded that determining the appropriate hydromodule has a very significant weight in costs, since it determines the power required in motors and transformers, increasing this way energy consumption.

An increase in the use of irrigation for crops, according to Hernández (2010), requires a greater exploitation of water resources and energy resources to achieve higher productions with high and stable yields.

The electrical central pivot machines have an important weight within the agricultural productions in Cuba, but as a result of the electrification and modernization of this irrigation technique, energy consumption has increased as a consequence of the modernization (Mujica and López, 2010).

CONCLUSIONS

- When irrigation is programmed based on the evaporative demand of the atmosphere and the humidity present in the soil, the total net norm is reduced by 23%, protecting the aquifer from saline intrusion.
- Consequently, the reduction in the number of irrigations and the rotation time of the central pivot machines, without failing to apply the necessary norm to the crop, would contribute to the reduction of energy consumption by 8.8% compared to the current ones in Güira de Melena Agricultural Company.
- The application of energy audits in irrigation allowed knowing that irrigation programming alone does not guarantee a reduction in energy consumption, another aspect of interest must be considered, such as the correct pump-motor-area relationship.

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