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ORIGINAL ARTICLE

Evaporation and Drag Losses in Different Techniques of Sprinkler Irrigation

Pérdidas por evaporación y arrastre en diferentes técnicas de riego por aspersión

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ABSTRACT: With the objective of comparing the potential values of evaporative and wind drag losses in different techniques of sprinkler irrigation in Camagüey Municipality, a study was carried out for the predominant conditions in UBPC Victoria II, belonging to Empresa Agropecuaria Camagüey. The techniques studied were the central pivot machines, the winder irrigation machine, the sprinkler irrigation system and the micro sprinkler. Drop size, wind speed in the maximum height of irrigation water, drop time of flight and steam pressure deficit were valued. The results indicate that the potential evaporative and drag losses under the predominant conditions in Camagüey Municipality, reach values among 7,5 % in the irrigation with micro sprinkler, 7,7 % in the irrigation with central pivot machines, 8,6 % with sprinkler irrigation systems and 9,2% in the winder irrigation machine. Nevertheless, in this technique, under conditions of wind speeds bigger than 3,1 m/s, they could overcome the value of 15 %, considered as permissible maximum limit for the execution of satisfactory air irrigation.

Keywords: Efficiency, Diameter of Drops, Height of the Jet, Wind Speeds.

RESUMEN: Con el objetivo de comparar los valores potenciales de pérdidas por evaporación y arrastres por el viento en diferentes técnicas de riego por aspersión en el municipio Camagüey, se realizó un estudio para las condiciones predominantes en la UBPC Victoria II perteneciente a la Empresa Agropecuaria Camagüey; las técnicas estudiadas fueron las máquinas de pivot central, el enrollador, el sistema de riego por aspersión y la microaspersión; fueron valorados el tamaño de gota, la velocidad del viento en la máxima altura del chorro, el tiempo de vuelo de las gotas y el déficit de presión de vapor. Los resultados indican que las pérdidas potenciales por evaporación y arrastre en las condiciones predominantes en el municipio Camagüey alcanzan valores de 7,5 % en el riego con microaspersión, 7,7 % en el riego con máquinas de pivot, 8,6 % en los sistemas de riego por aspersión y 9,2 % en el riego con enrollador con aspersor, esta tecnología en condiciones de velocidades del viento superiores a 3,1 m/s pudiera superar el valor del 15 % considerado como límite máximo permisible para la ejecución de un riego por aspersión satisfactorio.

Palabras clave: eficiencia, diámetro de gotas, altura del chorro, velocidad del viento.

INTRODUCTION

Given that water is an increasingly scarce natural resource and the energy associated with pressurized irrigation systems is increasingly expensive, it is essential that the application of irrigation water be carried out in an increasingly efficient way, in order to increase agricultural production with less availability of water and energy.

Sprinkler irrigation implies a more or less intense and uniform rain on the plot with the aim that the water infiltrates at the same point where it falls. The process of applying water from a sprinkler consists of a high-velocity jet of water that diffuses into the air in a set of drops, distributing itself over the surface of the ground, with the aim of achieving a uniform distribution among several sprinklers (Tarjuelo , 2005).

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This author states that during sprinkler irrigation, a part of the water emitted by the emitters can be lost by evaporation and wind drag (EDL), these losses can become significant.

The evaporative losses in the air depend mainly on the ambient humidity, air and water temperature, height of the emitter, size of the drops and wind speed. Drag losses depend on the wind speed, size of the drops and distance they have to travel to reach the ground, and on qualitative factors such as the type of sprinkler, height above the ground, and type and diameter of the nozzle used. Wind speed has often been considered as the variable that most affects EDLs (Tarjuelo et al., 2000).

Keller and Bliesner (1990) also indicated reference evapotranspiration as one of the parameters to be considered, a variable that integrates all the aforementioned meteorological variables.

The effect of wind on irrigation uniformity in sprinkler irrigation systems has been studied by various authors, who coincide in highlighting the fundamental role of wind in evaporation and drag losses produced during the application process (Bonet and Guerrero, 2016).

The EDL variable presents a tendency to decrease slightly from the beginning of the day until around 6:00 or 7:00, later, there is a rise in the estimated values of EDL until 15:00-16:00 GMT when maximum values are reached. Finally, there is a descent until the end of the day. In the periods from 11:00 a.m. to 7:00 p.m. (particularly those from 3:00 p.m. to 5:00 p.m.), sprinkler irrigation is not recommended because the probability of occurrence of EDL values greater than 15% is relatively large. . During the night, the effect on EDL of variables such as wind speed, relative humidity and temperature are less influential (Dechmi et al., 2003).

Tarjuelo (2005) refers that the uniformity of distribution on the surface has great dependence on the action of the wind, in intensity and direction, constituting the main distorter of the uniformity of distribution. It plays a fundamental role in the "loss by evaporation and drag" produced during the application process and where the size of the droplet and the length of its fall trajectory are fundamental factors.

This author points out that, to reduce the effect of wind in irrigation, the current trend in sprinkler systems is towards the use of low pressure, where the proper design of the emitters plays a fundamental role. It is recommended that emitters should have the maximum range and medium droplet size (1.5-4mm), which reduces wind distortion (and its effect on uniformity of water application) and evaporative and wind drift losses. In addition, they allow night irrigation (due to less evaporation, wind speed and energy cost) and are easy to use and automate.

Traditionally, it has been considered that each irrigation system is characterized by certain values of uniformity and efficiency, however, Keller et al. (1981) cited by Bonet and Guerrero (2016), indicated that uniformity depends much more on the management of irrigation systems than on the type of system used.

FIGURE 1. UBPC "Victoria II" satellite image. Source: Google Earth 2020.

In general, during irrigation with sprinkler irrigation technologies, the necessary attention to EDL is not usually given, because of that, the objective of this work is to compare the potential values of evaporation losses and wind drag in different sprinkle irrigation techniques in the Camagüey Municipality.

MATERIALS AND METHODS

Scenery

For the study of the potential behavior of the PEAs, the climatic conditions of Victoria II UBPC located in Camagüey Agricultural Company, in the municipality of the same name, were taken as reference (Figure 1).

Camagüey Municipality is located in the center of Camaguey Province, bordered to the north by the municipalities of Esmeralda, Sierra de Cubitas and Minas, to the south by Vertientes, to the west by Florida and to the east by Jimaguayú and Sibanicú. It presents characteristics typical of a tropical climate of seasonally humid equatorial forests of savannah with humid summer and with a comparatively notable tendency to continental character within the country. In its physical-geographical condition, the plains predominate.

For the study, the UBPC "Victoria II" belonging to Camagüey Agricultural Company, is taken as a reference, as it is the productive unit with the highest level of aerial irrigation activity in the municipality. It has a total area of 403.0 ha distributed in 17 farms, of which 144.0 ha are under irrigation, including 82.0 ha with sprinkler irrigation linked to six semi-stationary systems (medium pressure) and 62.0 ha of irrigation with five electric central pivot machines (Rodríguez, Bonet, Mola and Guerrero, 2018).

For the climatic characterization of the UBPC, the data corresponding to the meteorological station of

Camagüey (78355) was used, located at 21º24' North latitude and 77º51' West longitude, with a height of 118 m above sea level, being this the closest and most representative station for the study area.

Studies carried out by Camagüey Meteorology Center (2022) indicate that the average temperature in the study area has oscillated between 22.2°C in January and 27.1°C in July, with an annual average of 24 .9°C; increasing considerably from the months of March to August, they begin to decrease slightly from September until the winter period is over. The mean minimum annual temperature is 20.8°C, ranging between 18.1 and 23.0°C in January and July and August, respectively, with an appreciable upward trend. Average maximum temperatures range from 27.7°C in January to 32.8°C in August with an average annual value of 30.4°C. The absolute maximum temperature record is 37.2°C. The behavior of the average relative humidity ranges from 71% in April to 82% in October, with a historical average value of 77%; the months from September to December show the highest values. The predominant course or direction of the wind is from the East with fluctuations in average monthly speeds between 2.4 and 3.8 m/s, showing the lowest speeds in September and the highest in March.

For the evaluation of evaporation and drag losses, the most represented sprinkler irrigation techniques in the province were selected (Figure 2): central pivot machine, winder (with sprinkler), sprinkler irrigation system and micro-sprinkler irrigation technique.

Characteristics of the Systems Evaluated

Electric center pivot machine. BAYATUSA model; No. towers: 3; length: 202m; height: 2.90m; diffuser nozzles: 102; flow rate: 14L/s; working pressure: 200 kPa.

Winder with sprinkler, Komet Twin 160 model. Sprinkler. Pressure: 350 kPa; : 20 L s^{-1}; range: 40.0m; nozzle diameter: 31.4 mm; sweep angle: 220º; discharge angle: 24º; Pipeline. Diameter: 110mm; length: 340 m.

Sprinkler irrigation system. Semi-stationary type of 1ha. Sprinkler. Model F-46; nozzle: 3.5 x 2.3mm; working pressure: 250 kPa; range: 12m; flow rate: 900 L/h, discharge angle: 23º.

Micro-sprinkler irrigation system. Microjet microsprinkler technique. Jet angle: 2 x 140º mm; diameter: 1mm; flow: 40 L/h; range: 1.5m; working pressure: 150 kPa.

Droplet Size

The size of the sprinkler's drop of water influences in various ways when it hits the ground and the crop; large drops, due to their kinetic energy, can erode the ground upon impact; small drops, especially in areas with strong winds, being dragged more easily, can reduce the uniformity and efficiency of irrigation (Tarjuelo et al., 2000).

Dechmi et al. (2003), refers that small drops are ideal for clayey soils as long as there is no problem of high wind speeds, those with medium size are ideal for silty soils and moderate wind speeds and finally, the largest drops are ideal for sandy and porous soils, even with strong winds.

As the pressure increases and the nozzle diameter increases, the Thickness Index (IG) represents the size of the drop. Table 1 shows the diameter and pressure parameters for each irrigation technique, taken from the information provided by the manufacturers (TUSA, 2007; IIRD, 2010; Komet Twin, 2012; CICMA, 2019).

These parameters indicate that comparatively the largest drops are produced in the winder system with sprinkler, followed by sprinkler irrigation, while the pivot and microjet machines present the lowest values.

A criterion evaluates the quality of the rain based on the relationship between the working pressure and the nozzle diameter for irrigation with high and medium pressure emitters, and nozzle diameters greater than 16 mm (Table 2).

Applying this qualitative evaluation criterion for sprinklers in winder technology, the category of very thick drops is obtained, which indicates that good irrigation quality results should not be expected with this technique.

According to Tarjuelo (2005), the drag by the wind varies greatly with the size of the drop produced by

FIGURE 2. Irrigation techniques evaluated.

TABLE 1. Indicators that determine droplet size in sprinkler irrigation techniques evaluated

Technique	d (mm)	P (kPa)
Center pivot machine	1,8 - 5,6	200
Winder with sprinkler	31,4	350
Medium pressure sprinkler irrigation system	3,5 x 2,3	250
Micro sprinkler	1,0	150

d: Nozzle diameter; Q: Working pressure

the sprinkler. The smaller droplet size index implies smaller droplets that are more easily carried by the wind and facilitate greater evaporation under equal climatic conditions (wind speed, temperature and relative humidity). This author states that the losses by evaporation and dragging decrease rapidly when the droplet diameter goes from 0.3 to 1.0 mm.

Other authors such as Playán et al. (2005), deduce from their tests that the evaporation of the drops in sprinkler irrigation is practically negligible from a droplet diameter of 1.5 to 2.0 mm.

Small drops are easily carried by the wind, distorting the water distribution pattern and increasing evaporation, while thick drops have great kinetic energy, which is transferred to the soil surface (Faci et al., 2001, cited by Bonet and Guerrero (2016). This indicates that in relation to the size of the drops, the most favorable conditions for the production of EDL occur in winder sprinkler irrigation and the most unfavorable in irrigation with a micro-sprinkler.

Jet Height

Different aerial irrigation technologies present different behaviors of water displacement from when it leaves the nozzle until it reaches the soil.

Both the height of the nozzle and the way the water jet is projected condition different heights of the water and travel times from the projection of the jet until it reaches the irrigated soil.

While in the pivot machines, the projection of the jet is carried out from the nozzles downwards, in the rest of the evaluated technologies the projection of the jet is upwards, with the height reached in relation to the position of the nozzles being the minimum in irrigation by micro-sprinkling and very significant in winder sprinkle irrigation. (Figure 3).

The height of the crop influences the EDL, when the crop is higher the flight time of the drop and, therefore, the PEA are lower. At the same height of water emission by the sprinklers, the journey of the water to the crop lasts longer in low-growing crops; therefore, due to differences in the wind profile, the probability that a given drop of water evaporates or is washed away from the irrigated plot is much higher (Tarjuelo, 2005).

Table 3 shows the values of maximum height of the jet calculated from the height of the nozzle, the angle of departure, projection and reach of the jet.

TABLE 2. Category of droplets according to the Pressure / Nozzle Diameter relationship

P/d	Droplet category
< 1500	Very thick
1500 - 1600	Thick
1600 - 2000	Medium
2000 - 2200	Fine
2200 - 2600	Very fine
2600	Heavily pulverized

Source: Tarjuelo et al. (1994)

FIGURE 3. Projection of the stream in Winder and Sprinkler Irrigation Systems.

TABLE 3. Maximum height of the jet

Technique	H (m)
Center pivot machine	1,50
Winder with sprinkler	18,0
Sprinkler irrigation system	5,80
Micro sprinkler	0,70*

H: Maximum height of the jet. *Includes height of the flowerbed in the Organoponics.

As the height of the jet increases, the travel time of the water in the air increases, at the same time, a greater height of the jet exposes it to higher wind speeds. These factors condition the potential increase in EDLs, therefore, equally from other conditions, greater losses must be expected in irrigation with the use of the winder sprinkler irrigation and lower in irrigation with micro-sprinkler.

Wind Speed

Results of studies indicate that for wind speeds greater than 4 m/s, 47% of the total losses are due to drag and 53% are due to evaporation, while with winds less than 4 m/s these values are 25 and 75%, respectively (Tarjuelo et al., 2000).

Faci and Bercero (1991) and Tarjuelo et al. (1994), cited by Cisneros et al. (2019), place the general wind speed limit above which it is not advisable to irrigate in sprinkler irrigation between 2.5 and 3.5 m/s, and establish a classification (Table 4).

According to information provided by INSMET Camagüey (Camagüey Meteorology Center, 2022), the prevailing wind speeds at a height of 1.5 m in the studied area remain between 2.4 and 3.8 m/s during daylight hours, which classifies them as in the medium speed range.

Based on the information available on the behavior of the wind speed in the area, the average value of 3.1 m/s was taken as a reference, with which the wind speeds at the maximum heights of the jet projection in each technique were estimated. (Table 5).

TABLE 4. Wind speed classification for sprinkler irrigation

Terms	Ws (m/s)
Very windy	Ws ≥ 4
Medium	2 ≤ Ws ≤ 4
Favorable	Ws ≤ 2

TABLE 5. Wind speed at the maximum projection height of the jet

Technique	Vs (m/s)
Center pivot machine	3,10
Winder with sprinkler	8,10
Sprinkler irrigation system	5,44
Micro sprinkler	2,62

Maximum Flight Time of the Drop

The maximum flight time of the drops was estimated from the distance traveled from the nozzle, the nozzle diameter and the flow rate (Table 6).

In the case of pivot machines, the smallest and largest nozzles of the selected machine model are indicated (Table 5), it is observed that the flight time coincides, the same happens for the rest of the nozzles of the machine. For the calculation of the route of the drop, the maximum range, the height of the nozzle on the ground and the form of projection of the rain have been considered.

It must be expected that, the flight time in the case of the winder and the sprinkler irrigation system are slightly higher due to wind resistance, but the differences would not be significant.

The average EDL values estimated for corn were appreciably lower than the ones estimated in those same stations and with the same historical series for a prairie. These differences reflect the different wind profile that develops on both crops. In the case of the meadow, the distance that the water drops have to travel from the sprinkler to the crop is much greater, so the opportunity time for the evaporation of these drops or their drag by the wind is greater. In the night periods and in the early hours of the morning, the EDL for a maize crop were quite small and in a few cases they were higher than 15%, a threshold from which it would not be advisable to carry out sprinkler irrigation (Martínez et al. , 2005).

Vapor Pressure Deficit (VPD)

The VPD measures the difference, in terms of pressure, between the water vapor in the air and the saturation point of the air, which is the maximum amount that the air can carry at its current temperature; the full saturation point is also called the dew point.

The VPD can be obtained from equation 1 (Allen et al., 1998).

$$ea - es = 0{,}6108 \left\{\left[\exp\left(\frac{17{,}29Ta}{Ta + 237{,}3}\right)\right] - \left[\left(\frac{17{,}27Tdew}{Tdew + 237{,}3}\right)\right]\right\} \qquad (1)$$

where:

ea-es. Vapor Pressure Deficit (kPa);

Ta. Ambient temperature (^{o}C);

Tdew. Dew point (^{o}C).

Taking ambient temperature values of 22 ^{o}C as a reference, a characteristic value of the months with the highest intensity of the irrigation campaign in the study area, a VPD of 0.52 kPa is obtained.

TABLE 6. Maximum flight time of the drop

Technique	D (mm)	q	v	R	t
		(m³/s)	(m/s)	(m)	(s)
Center pivot machine	1,8	0,000039	0,15	2,12	14,13
	5,6	0,00038	0,15	2,12	14,13
Winder with sprinkler	31,4	0,0200	0,26	54,0	207,69
Sprinkler irrigation system	3,5	0,00015	0,16	13,5	84,37
	2,3	0,0001	0,24	8,1	33,75
Micro sprinkler	1,0	0,000011	0,14	1,51	10,78

D: nozzle diameter; q: caudal; v: velocity of the drop; R: maximum travel of the drop; t: flight time

Evaporation and Drag Losses (EDL)

Different methods have been described for the calculation of EDL, they have been described in different conditions and their results tend to be diverse.

For example, the method proposed by Yazar (1984), cited by Tarjuelo (2005), in which evaporation and wind drift are determined in isolation from evaporation and wind speed. Studying these two aspects separately has no practical significance.

For the purposes of this study, the EDLs have been estimated from equation 2 (Medina, 2006 cited by Martínez et al., 2005).

$$EDL = 4{,}85 + 0{,}37Ws + 3{,}34VPD \quad (2)$$

where:

EDL. Evaporation and drag losses (%);
Ws. Wind speed (m/s);
VPD. Vapor pressure deficit (kPa).

From the VPD value obtained (0.52 kPa) and the wind speeds considered for each technology, the EDL values shown in Table 7 are obtained.

It is observed that despite the low values of wind speed that affect micro-sprinkler techniques and central pivot machines, the EDL values exceed 7%, which indicates that the VPD has a significant weight in them.

Table 8 shows the results of the values obtained from EDL and their relationship with height and flight time.

The results of the evaluations show the highest EDL due to the wind in the irrigation technique using a winder with a sprinkler (9.23%), this indicates that the height reached by the jet and the flight time are more significant in said losses than the size of the drop. In practice, the EDL in irrigation techniques by sprinkler and winder with sprinkler must be significantly higher than the estimated values, due to the longer exposure time of the drops, a factor that the calculation method does not consider.

Talel et al. (2011) refer that the EDLs can reach values of up to 40%, mostly between 2 and 15%; above 15% irrigation is not recommended.

Martinez et al. (2005) express that some authors indicate that these losses are of the order of 5-10% under conditions of moderate evaporative demand; however, others have indicated that the EDL can exceed 20%.

According to Tarjuelo (2005) the main effects of wind in sprinkler irrigation are suffered by fixed or stationary irrigation systems and irrigation cannons compared to pivot systems. The lack of uniformity in an irrigation as a consequence of the action of the wind can be compensated in the successive irrigations as the wind conditions change normally, this improvement in accumulated uniformity of several irrigations will be more profitable for the crop than the higher the frequency of irrigation.

Keller and Bliesner (1990) cited by Bonet and Guerrero (2016) point out that the EDL should range between 5 and 10%, however they recognize that when conditions are severe the values can be considerably higher.

Rodriguez et al. (2012) cited by Uribe et al. (2021), state that the wind has a great impact on the deterioration of irrigation quality parameters, reducing the effective range radius of the sprinkler. In field evaluations carried out in sprinkler irrigation systems, they were able to verify that as the wind speed increases, the effective range of the sprinkler decreases reciprocally, which brings with it poor water distribution on the plot.

Tarjuelo et al. (1995) cited by Bonet and Guerrero (2016) refer that a good irrigation is not the one that uniformly wets the soil surface, but the one that stores water uniformly in the soil profile. They consider that among the disadvantages of sprinkler irrigation is the affecting the uniformity of irrigation when the wind in the region where it is applied is strong.

TABLE 7. Losses by evaporation and drag per irrigation technique

Technique	Ws (m/s)	DPV (kPa)	PEA (%)
Center pivot machine	3,10	0,52	7,73
Winder with sprinkler	8,10		9,23
Sprinkler irrigation system	5,44		8,60
Micro sprinkler	2,62		7,55

TABLE 8. Evaporation and drag losses, in relation to the height of the jet and flight time

Technique	EDL (%)	H (m)	t (s)
Center pivot machine	7,73	1,50	14,13
	5,60		
Winder with sprinkler	9,23	18,0	207,69
Sprinkler irrigation system	8,60	5,80	33,75 - 84,37
Micro sprinkler	7,55	0,70	10,78

Martinez et al. (2005) consider that the EDL do not act in an absolute negative way; because of the EDL during sprinkler irrigation, the microclimatic conditions are modified, producing a decrease in the VPD as well as in the air temperature. This contributes to the reduction of crop transpiration and, therefore, to the conservation of humidity in the soil, although, in climatic conditions of the region studied, these microclimatic changes during sprinkler irrigation are reduced to a few hours after irrigation.

CONCLUSIONS

- Potential losses due to evaporation and dragging under the prevailing conditions in Camagüey Municipality reach values of 7.55% in micro-sprinkler irrigation, 7.73% in the central pivot machine, 8.60% in sprinkler irrigation and 9 .23% in the irrigation with winder with sprinkler.
- In conditions of wind speed higher than 3.1 m/s, the losses due to evaporation and dragging in the winder irrigation technology could exceed the value of 15% considered as the maximum allowable limit for the execution of satisfactory sprinkler irrigation.

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