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CLASSIFICATION AND USE OF EMITTERS USED IN SPRAY IRRIGATION SYSTEMS

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KEYWORDS

drip irrigation, emitter performance, irrigation efficiency, sprinkler irrigation.

ABSTRACT

This efficiency in the application of water is associated with the evolution of irrigation equipment and systems and can be illustrated by the drippers in the case of localized irrigation, the sprinklers in the case of sprinkler irrigation, and the low-pressure emitters used in a central pivot. Given the context presented, this study aimed to carry out a theoretical approach on the classification and use of emitters used in pressurized sprinkler irrigation systems, carrying out bibliographical research on the subject. The research is exploratory, where articles and books with related subjects were researched: "classification and use of emitters used in pressurized sprinkler irrigation systems". The research was carried out via the Google Academic platform and in libraries. The type of emitter to be chosen depends on many factors that influence the efficiency of the system. Therefore, a well-designed project, with the correct choice of the type of emitter, maximizes the application efficiency, minimizes energy expenditure, and increases the producer's profitability.

INTRODUCTION

Irrigation intensified in Brazil from the 1970s onwards, driven by the expansion of the agricultural frontier to regions with less favorable physical and climatic characteristics, by the greater economic viability of pressurized irrigation, and by the benefits associated with increased productivity. Several government initiatives were carried out and although they did not fully reach the planned goals, several collective works of common use and basic infrastructure were carried out, in addition to the provision of legal, institutional, technical, and financial support, which boosted the expansion of the activity, in particular in stimulating the private sector through basic infrastructure and financing (Althoff & Rodrigues, 2019; ANA, 2021; Cabral et al., 2022).

In arid and semi-arid regions, water has become a limiting factor for urban, industrial and agricultural development. Even areas with abundant water resources, but insufficient to meet high demands, experience conflicts of use and suffer consumption restrictions that affect economic development and quality of life. Under these conditions, reuse and conservation have become the key words in terms of management, in regions with low availability or insufficient water resources (Hespanhol, 2018; Angelakıs et al., 2020).

Historical series show that annual increases in the irrigated area in Brazil have been strong in recent decades, intensifying in recent years. Among the pressurized irrigation methods and systems, it is observed that localized irrigation (drip and micro-sprinkler) and center-pivot sprinkler - accounted for about 70% of the increment of the irrigated area between 2006 and 2019. How these methods are more efficient in the use of water, with the increase of its participation in national irrigation, even with a growth of the irrigated area of 76% until 2040, the water demand should grow only 66% (Althoff & Rodrigues, 2019; ANA, 2021).

This efficiency in the application of water is associated with the evolution of irrigation equipment and systems and can be illustrated by the drippers in the case of localized irrigation, the sprinklers in the case of sprinkler irrigation, and the low-pressure emitters used in a central pivot. The new technologies present in drippers allow the application of very low volumes of water over time while increasing the uniformity coefficient. Sprinklers, on the other hand, evolved to apply larger drops, better distributed

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along with the land and operating at low pressures (Lopes, 2017). The center pivot, initially, was designed with impact emitters, which were installed over the pipes, about 4.6 meters high and required high service pressure, currently, emitters have evolved allowing a larger wet diameter with a lower precipitation rate instantaneous, located at 2.0 meters above the ground with flexible descent hangers.

The differences in equipment are significant, ranging from the composition of the material used to the form of water application, which provides greater efficiency in terms of water and energy, although the conceptual bases of the systems are the same. It is clear that technological advances in irrigated agriculture go far beyond the development of new irrigation equipment, it is also possible to point out the automation of systems, from pumping to the operation of the equipment itself (Lopes, 2017).

Given the context presented, this study aimed to carry out a theoretical approach on the classification and use of emitters used in pressurized sprinkler irrigation systems, carrying out bibliographical research on the subject.

MATERIAL AND METHODS

The research is exploratory, where articles and books with related subjects were researched: "classification and use of emitters used in pressurized sprinkler irrigation systems". The research was carried out via the Google Academic platform and in libraries.

Research and development of irrigation equipment in Brazil

The development phase of irrigation in Brazil, which began in the 1980s, was marked by a clearer division of roles between government and private action in the development of irrigation programs, with the government playing a leading role in the execution of collective works in common use (public projects), basic infrastructure (energy transmission and distribution, macro-drainage, logistics) and support (financing, research, extension) (Multsch et al., 2020; ANA, 2021).

Even if these government initiatives did not fully achieve the planned goals, several collective works of common use and basic infrastructure were carried out, in addition to the provision of legal, institutional, technical, and financial support, which boosted the expansion of the activity, especially in the stimulus to the private sector through basic infrastructure and financing (ANA, 2021; Barros et al., 2023).

Brazil is one of the few countries in the world where all the major world manufacturers of irrigation equipment and systems are present with manufacturing facilities. The beginning of the manufacture of irrigation equipment in Brazil took place between the 1970s and 1990s, many factories were built during this period, betting on the potential of the Brazilian market and taking advantage of the economic protectionism that made it difficult to import irrigation systems and equipment (Lopes, 2017).

The market composed of companies with national, North American, Israeli, European, and Indian capital. It is important to highlight the major presence of the national capital industry in the supply of components for irrigation systems, such as PVC pipes and similar, hydraulic pumps, electric motors, components, and electric cables, etc. (Lopes, 2017).

Companies have constantly invested in improving their products and updating their technology. The technical base that has been built in Brazil should continue to be the object of improvement, which depends on partnerships with public agencies, international organizations, the user sector, specialized consultants, and universities and research centers (Multsch et al., 2020; ANA, 2021; Morais et al., 2021).

RESULTS AND DISCUSSION

Sprinkler irrigation

Sprinkler irrigation has several advantages when compared to flood, strip and furrow methods, especially in the much greater control of water applications, for example, with greater capacity to apply smaller amounts of water more frequently and even locally (Thorp, 2019). It is adaptable to most soils and topography, the systems being flexible in design and operation. The efficiency of sprinkler irrigation typically ranges from 70% to 85%, with center pivots and linear motion systems being the most efficient systems (Allen & Macadam, 2020).

Many sprinkler systems used in Brazil are still of the conventional portable type. However, in larger areas and to minimize the use of labor in irrigation, the use of mechanized systems has grown, particularly the central pivot, with varying levels of automation. Sprinkler systems in general are classified into two main groups: conventional systems (permanent fixed, temporary fixed, semi-fixed and portable) and mechanized systems (linear system, rolling lateral, center pivot, self-propelled and direct assembly) (Testezlaf, 2017; Bernardo et al., 2019).

The irrigation equipment used plays an important role in water use and irrigation efficiency (Ferrarezi et al., 2020). Many operational and design parameters can affect the uniformity of water distribution, these parameters include sprinkler nozzle diameter, sprinkler type, service pressure, sprinkler height, irrigation time and duration, and weather conditions (Al-Ghobari et al., 2018). Several researches (Miranda et al., 2019; Oliveira et al., 2020) are done to develop irrigation management practices and technologies that improve water productivity (Thorp et al., 2020).

Sprinkler

The main component of the sprinkler irrigation system, the sprinkler, is a key part of the system sizing (Ara et al., 2021). Sprinkler performance has a direct effect on the quality of the entire sprinkler irrigation system (Yan et al., 2020). During the operation of the sprinklers, the water jet passes through the nozzle and is launched into the air at high speed, fragmenting into droplets due to the friction between the air and the water flow, precipitating on the soil surface similar to rain (Testezlaf, 2017).

In the absence of wind, droplet size and distribution patterns depend on the design of the nozzle and the fragmentation mechanisms associated with the flow, the service pressure of the sprinkler, and its height above the ground surface. In the presence of wind, its speed and direction will affect droplet sizes and distribution patterns, determining the intensity of the occurrence of drift water losses, causing low distribution uniformity and, consequently, low efficiency (Testezlaf, 2017).

Sprinkler design is primarily based on hydraulic performance, the diameter of the sprayed droplet, and the speed at which the droplet falls to the ground. These are important indices of nozzle spray performance when evaluating the quality of a sprinkler irrigation system (Xiang et al., 2021).

A suitable sprinkler irrigation system must guarantee a homogeneous application of water to the soil so that there is no restriction or excess water at any point in the irrigated area. Which sprinkler to use, with its respective arrangement, even with the knowledge and understanding of the manufacturers' catalogs is a difficult task, and this choice can define the success or not of a sprinkler irrigation system. A varied number of criteria can be used to classify a sprinkler (Table 1).

TABLE 1 - Classification of sprinklers according to different criteria.

Criteria	Classification	Characteristics
Rotational movement of the jet	Fixed	Diffusers or sprays
	Rotary	Impact, reaction and gears
Service pressure	Very low	P < 14,5 Psi
	Low	14,5 Psi < P < 29 Psi
	Average	29 Psi < P < 58 Psi
	High	P > 58 Psi
Angle of inclination of the jet	Normal	In between 25º e 35º
	Subcup	< 7º
Jet Cover Angle	Full circle	360º
	Sector	angles <360º
Number of nozzles	One nozzle	1
	Multiple nozzles	(>1)
Installation location	Surface	normal
	Buried	Retractable (popup)

Adapted de Testezlaf (2017).

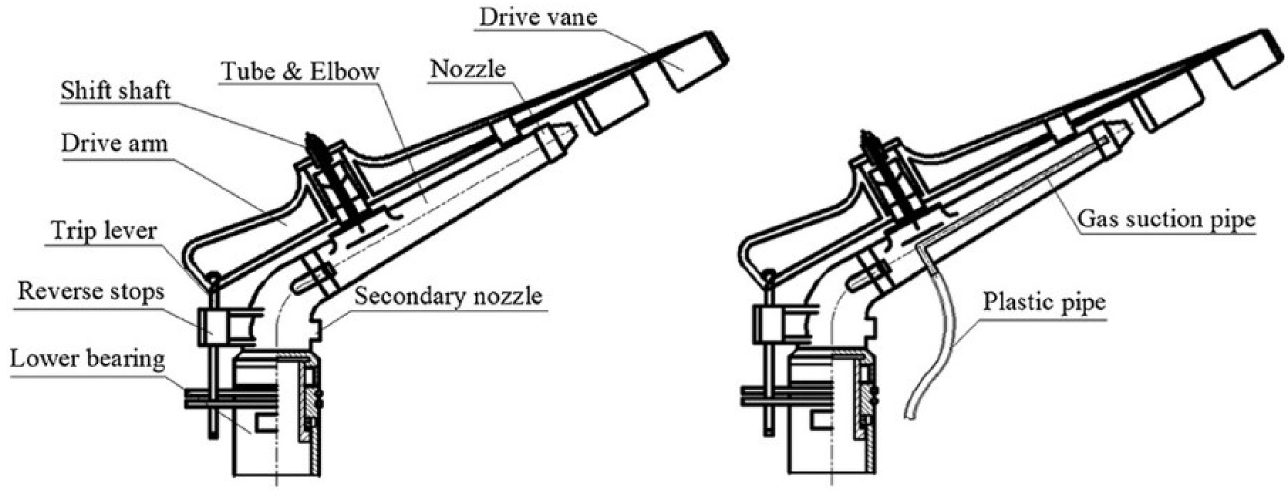
Classification of sprinklers according to different criteria

Rotational movement of the jet

Impact sprinklers

They are the most used and operate at low speed. Impact sprinklers are high-pressure sprinklers that produce jets of water over a large horizontal distance. They spread the water in small droplets that are easily blown away by the wind, causing greater losses by evaporation, especially in arid regions (Li et al., 2019).

Recent research shows that a better droplet atomizing effect can be obtained even if a small amount of gas is introduced into the water jet. Thus, the Aeration Impact Sprinkler (AIS) is an innovative type of sprinkler with constant sprinkler rotation. The working condition of the AIS is based on a two-phase flow fluid (air-water) rather than a commonly used single-phase impact sprinkler (water only) (Figure 1). The idea comes from the sprinklers used in firefighting (Xiang et al., 2021).



Source: Xiang et al. (2021).

FIGURE 1. Difference between conventional impact and aeration impact sprinkler operating mechanism.

The AIS rotation principle is stationary, being different from other types of impact sprinklers and generating drops with different characteristics.

Gear Sprinklers

These sprinklers perform a continuous rotation thanks to the passage of water through a gear mechanism, connected to the emitter body. Continuous rotation results in more even water distribution than impact sprinklers. They are more expensive than impact sprinklers and their use is limited in agriculture, being more widespread in gardening (Valverde & Malán, 2019) (Figure 2). A widespread use of these emitters has been in livestock confinement areas for the purpose of lowering dust. Its operation is extremely silent and does not stress the animal.

Source: Valverde; Malán (2019).

FIGURE 2. Gear Sprinkler.

Reaction Sprinklers

They are an evolution of impact sprinklers. They produce a strong, compact water jet systematically interrupted by a diffuser, allowing water patterns to fill. In addition, it distributes light drops of water, preventing soil sealing (Bellido et al., 2018) (Figure 3).

Source: Bellido et al. (2018).

FIGURE 3. Reaction sprinkler.

They have one or more nozzles oriented so that the reaction to the change of direction of the water movement produces the rotation of the sprinkler. Its use is very common in gardening, horticulture, nurseries, etc (Valverde & Malán, 2019).

Fixed or spray sprinklers

Impact sprinklers are being replaced by low-pressure sprinklers commonly classified as fixed plate emitters (FSPS) and rotary plate emitters (RSPS), which produce very different droplet size distributions and water application patterns (Jiao et al., 2017).

Compared to RSPS, the fixed plate sprinkler (FSPS) offers the advantages of relatively low working pressure, high wind resistance, and low cost. The working principle of FSPS (Figure 4) is simple. The water jet hits a grooved plate, breaking the jet into several parts equal to the number of grooves on the plate. The water distribution pattern of a single FSPS resembles a wet circular crown (Sayyadi et al., 2014).

Source: Catalog Senninger Irrigation (2020).

FIGURE 4. LDN Senninger spray sprinkler.

Service pressure

They are classified into very low, low, medium, and high-pressure sprinklers. The operating pressure of a sprinkler, together with other characteristics of the components of this type of device, determines the flow rate, the range, the degree of spraying of the drops, and the intensity of precipitation provided by the device.

Very Low Pressure Sprinklers

Very low-pressure devices (with pressure requirements between 5.8 and 14.5 Psi) have been marketed for the past 40 years as an alternative to reduce energy bills. Furthermore, it is known that reducing the pressure in the sprinklers can modify the pattern of radial application and reduce the quality of irrigation in terms of uniformity (Rovelo et al., 2019a).

They are usually stationary or rotating by reaction and comprise the special types of sprinklers used in cultivation in protected environments, orchards, gardens, and also central pivot (Rovelo et al., 2019b).

The most common sprinklers used in self-propelled irrigation machines are FSPS (fixed plate emitters) and RSPS (rotating plate emitters) (Figure 5) (Rovelo et al., 2019a). The characterization and simulation of spatial distribution patterns of water, energy losses, droplet size distribution, drift, and evaporation losses for FSPS and RSPS have been the subject of numerous studies (Zhang et al., 2018).

Thanks to the insertion of the rotary plate emitters, the irrigation center pivot equipment, which uses it, increased the uniformity coefficients of the equipment, going from 85% to up to 95%. Without a doubt, it was a big step forward in application quality and increased efficiency.

Source: Catalog Senninger (2020).

FIGURE 5. Senninger manufacturer's i-WOB UP3 rotary card emitters.

Low pressure sprinklers

Traditional sprinkler irrigation systems were generally designed to operate with at least 43.5 Psi of pressure (Robles et al., 2017). Compared with the service pressure of emitters used in spot irrigation (2.9-14.5 Psi), the operating pressures of the sprinklers were extremely high (Cai et al., 2018). They are sprinklers that work with pressures between 14.5 and 29 Psi.

On the side-movement and center-pivot irrigation machines, reductions in energy requirements were successfully achieved, replacing traditional impact sprinklers with spray-type sprinklers (Robles et al., 2017).

Studies with rotary sprinklers working under low pressure (less than 43.5 Psi) are not common, although these sprinklers have wide application in agriculture and are suitable for sloping farmland and uneven terrain (Zhang et al., 2019).

The low-pressure rotary sprinkler (Figure 6) is designed for use in fixed sprinkler systems and can potentially achieve a high-quality water application under low working pressure if the structure is designed correctly (Chen et al., 2020).

Source: Catalog Nelson (2020).

FIGURE 6. R33/R33LP Rotator Nelson Low Pressure Rotary Sprinkler.

Medium pressure sprinklers

They work with service pressures ranging from 29 to 58 Psi and are the most used in conventional sprinkler irrigation systems. They are sprinklers equipped with one or two nozzles whose diameters range between 4 and 7 millimeters. When this type of sprinkler has two nozzles, the larger diameter nozzle throws rain on the area adjacent to the axis of the sprinkler, while the smaller one wets the peripheral part of the circle.

Some studies have been done comparing sprinklers considered to have low service pressure (29 Psi) and medium service pressure (43.5 Psi). Robles et al. (2017) indicated that at mean (standard) pressure, 43.5 Psi, the water jet breaks enough to produce an adequate pattern of conical water distribution. As the pressure is reduced, the pattern takes on a ring shape, reducing the uniformity of the superimposed configuration. The relationship between wind speed and irrigation uniformity evaluated was stronger for the mean pressure (43.5 Psi). The effect of treatments of different service pressures (43.5 Psi and 29 Psi) on the cost of electricity depends on the topography of the network and these authors concluded that it is feasible to reduce power requirements by reducing the sprinkler operating pressure from 43.5 Psi to 29 Psi without affecting the yield of the crop.

Zapata et al. (2018) also worked with pressures of 29 and 43.5 Psi. They analyzed the differences in droplet size distribution and water jet distribution curves, collecting rainfall intensity at different heights of the sugarcane in relation to the ground. The water distribution curve showed fewer differences between its beginning and end in sprinklers working with a pressure of 43.5 Psi and the droplet size was smaller. The water jet overlap simulation in a rectangular 18x18 m arrangement revealed that the effect of sugarcane elevation on the uniformity coefficient (CUC) was large for the low-pressure treatments (29 Psi) and irrelevant for the medium pressure treatment (43.5 Psi).

High Pressure Sprinklers

They operate with service pressures above 58 Psi, with ranges above 30 meters and flow rates above 6.12 $m^3 h^{-1}$. A system that uses high-pressure sprinklers is self-propelled, which is widely used for irrigation of sugarcane, corn, and coffee (Testezlaf, 2017; Bernardo et al., 2019). This sprinkler is also widely used at the end of center pivot irrigation equipment. It can increase the irrigated radius up to 32 meters of useful range. However, its use in pivot is very regionalized in Brazil.

High-pressure sprinklers have a wider wetting diameter compared to low-pressure sprinklers. Therefore, to apply a certain depth of water to a specific soil using the high-pressure sprinkler, the applied water will spread over a wide area due to the wide wetting diameter and therefore result in a low instantaneous application rate. If the low-pressure sprinkler is used to apply the same depth of water, the same amount of water will spread over a smaller area, resulting in a higher instantaneous application rate (Von Bernuth & Gilley, 1985).

Some studies on the kinetic energy distribution of cannon-type sprinklers are being carried out with the aim of determining a service pressure to reduce the system's energy consumption (Ge et al., 2018).

Source: Catalog Comet (2021).

FIGURE 7. Comet Twin 101 ultra high pressure sector sprinkler.

Angle of inclination of the water jet

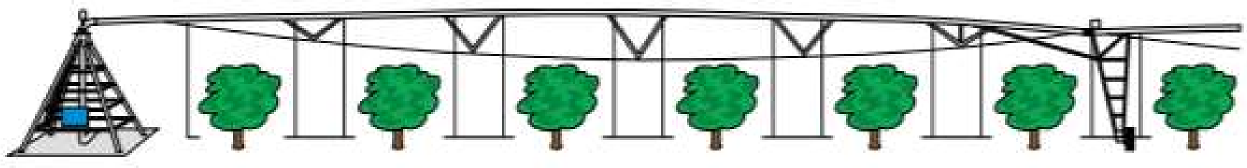
The sprinkler spray angle is expressed by the angle of inclination of the stream of water flowing from the nozzle in relation to the ground (Antypas & Dychenko, 2016). Literature and manufacturers provide different information about angle values, ranging from small angles with about 7 degrees to larger angles with 25 degrees of the jet.

The most important factor controlling the determination of the proper tilt angle is the spray radius, ie the level to which the water droplets dispensed from the spray nozzle reach. Therefore, a search is made for the angle of inclination of the water jet, which will give a larger radius. An increase in the spray radius can increase the distance between the sprinklers, which is desirable for the irrigator (Antypas et al., 2020), as it reduces the number of sprinklers needed in the area.

The angle of inclination of the water jet and the impact of the drop are closely related to the distribution of the drop's shear stress and the infiltration of water into the soil. To investigate the radial distributions of drop impact angles and to establish the relationships between drop impact angle and sprinkler distance, Hui et al. (2021) used a ball sprinkler under different pressures and different nozzle sizes. The authors reported that the greater the horizontal distance in relation to the sprinkler, the smaller the angles of impact of the drops with the ground. Thus, droplets that fall farther from the sprinkler can generate higher shear stresses due to their lower impact angles.

This and other studies suggest that reasonable service pressure and sprinkler organization should be selected to reduce droplet shear stress and improve the performance of sprinkler irrigation systems. Although the nozzle diameter has a certain effect on the maximum shear stress value, the overall effect is not significant (Zhang et al., 2018; Hui et al., 2021).

Sprinklers with small jet angles are widely used on fruit trees in sub-canopy irrigation. Central pivot irrigation equipment also uses special sub-canopy sprinklers to irrigate between the rows of citrus trees, which are planted in circular planting. Below, Figure 8 shows the assembly scheme of the sub-cup emitters used in the center pivot.



Source: Catalog Valley (2021).

FIGURE 8. Center pivot subcup sprinkler.

Jet Cover Angle

Generally, sprinklers are used to irrigate complete circles (360º), these are placed within the area to be irrigated. However, there are sprinklers equipped with a special device, which limits the wet area to a certain sector of the circle (less than 360º), they are called sectorial sprinklers (Figure 9). They are indicated for the edges of plots where corners and sides need to be watered. There are sector sprinklers in the market with a pre-set working angle (90º, 180º, 270º, etc.) and others in which the rotation is regulated from 0º to 360º (Valverde & Malán, 2019).

The irrigation center pivot end cannon sprinkler is regulated with a jet angle around 200 degrees. Its objective is to irrigate beyond the reach of low-pressure emitters commonly installed along the equipment radius.

Source: Catalog NaanDanJain (2020).

FIGURE 9. NaanDanJain 5022 SD PC Sector Sprinkler.

Number of nozzles

It can range from one to two nozzles of different sizes. The size of the nozzle, together with the type of sprinkler and the working pressure, influence the size, speed, and kinetic energy of water droplets. The largest nozzle has the function of irrigating the edge of the covered area and the smallest nozzle irrigates the area closest to the sprinkler (Liu et al., 2016).

Chen et al. (2020), working with the Nelson R33LP sprinkler, under different pressures, and with 3 different nozzle sizes, indicated that at given working pressure, the sprinkler precipitation intensity increased with increasing nozzle size. However, the size of the nozzle did not influence the volume and average size of the drops.

Several studies of viability (Oliveira et al., 2021; Gava et al., 2023) have been carried out to reduce the energy cost of sprinkler irrigation. For this, it is necessary to design new types of nozzles and water dispersion devices that can overcome poor distribution under low-pressure conditions (Issaka et al., 2020).

Installation location

They can be surface (Figure 10) or retractable (Figure 11). Retractable models are those that are below the level of the grass, not affecting the aesthetics of the landscaping, allowing garden pruning to be carried out normally. They only rise above the ground surface when they are pressurized (Testezlaf, 2017).

Source: Catalog RainBird (2020).

FIGURE 10. LF2400 Sprinkler Installed on RainBird Surface.

Source: Catalog RainBird (2020).

FIGURE 11. Series 5000 PLUS RainBird Retractable Sprinkler (pop-up).

Pop-up sprinklers have been widely used on golf and soccer courses with automated systems managed by software that are able to trigger them remotely.

CONCLUSIONS

The type of emitter to be chosen depends on many factors that influence the efficiency of the system. Therefore, a well-designed project, with the correct choice of the type of emitter, maximizes the application efficiency, minimizes energy expenditure, and increases the producer's profitability.

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