

Solar irrigator: analysis of its performance a home vegetable garden according to a Gaussian Distribution

Irrigador solar: análise do seu desempenho em uma horta caseira segundo uma Distribuição Gaussiana

Irrigador solar: análisis de su rendimiento en el jardín de una casa según una Distribución Gaussiana

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ABSTRACT

The maturation process of some vegetables depends on many factors, among the main ones are the amount of sunlight received in the form of infrared radiation, which is responsible for their growth, and the amount of water absorbed during the days, which plays a fundamental role in the biochemical process for the production of energy by the plant. Depending on the region, if the plant receives too little or too much solar radiation during the days and how it is irrigated determine its growth and production. This study aimed to analyze the performance of an automatic solar irrigator built with low-cost materials in a small beet crop, implemented in a region located 17 km from the city of Abaetetuba during the months of March, April, May, and June. The results showed that the irrigator had better performance in the month of June due to the balance between high temperatures (satisfying a Gaussian distribution) and the amount of water delivered. It was found that the performance of the solar irrigator, although satisfactory, did not have a good evaluation in the production of beets, thus it is not a determining factor in the production of this type of crop under the research conditions.

Keywords: irrigation, Gaussian distribution, home vegetable garden, solar radiation.

RESUMO

O processo de maturação de alguns vegetais depende de muitos fatores, dentre os principais, estão a quantidade de luz solar recebida, na forma de radiação infravermelha, sendo a responsável por seu crescimento, e a quantidade de água que absorve durante os dias, que tem papel fundamental no processo bioquímico para a produção de energia pelo vegetal. Dependendo da região, se o cultivar recebe pouca ou muita radiação solar durante os dias e a forma como esse é irrigado determinam seu crescimento e produção. Este trabalho objetivou analisar o desempenho de um irrigador solar automático construído com materiais de baixo custo em uma pequena cultura de beterrabas, implementada em uma região localizada a 17 km da cidade de Abaetetuba durante os meses de março, abril, maio e junho. Os resultados mostraram que o irrigador teve melhor desempenho no mês

de junho decorrente do equilíbrio entre as altas temperaturas (satisfazem uma distribuição Gaussiana) e quantidade de água entregue. Verificou-se que o desempenho do irrigador, embora tenha sido satisfatório, não teve uma boa avaliação na produção de beterrabas, assim não é fator determinante na produção deste tipo de cultura nas condições da pesquisa.

Palavras-chave: irrigação, distribuição Gaussiana, horta caseira, radiação solar.

RESUMEN

El proceso de maduración de algunas hortalizas depende de muchos factores, entre los principales están la cantidad de luz solar que reciben, en forma de radiación infrarroja, que es la responsable de su crecimiento, y la cantidad de agua que absorben durante los días, que tiene un efecto fundamental papel en el proceso bioquímico para la producción de energía por las plantas. Dependiendo de la región, si el cultivar recibe poca o mucha radiación solar durante el día y la forma de riego determinan su crecimiento y producción. Este trabajo tuvo como objetivo analizar el desempeño de un irrigador solar automático construido con materiales de bajo costo en un pequeño cultivo de remolacha, implementado en una región ubicada a 17 km de la ciudad de Abaetetuba durante los meses de marzo, abril, mayo y junio. Los resultados mostraron que el irrigador tuvo mejor desempeño en junio debido al equilibrio entre las altas temperaturas (satisfaciendo una distribución gaussiana) y la cantidad de agua entregada. Se encontró que el desempeño del irrigador, aunque satisfactorio, no tuvo una buena evaluación en la producción de remolacha, por lo que no es un factor determinante en la producción de este tipo de cultivo en las condiciones de la investigación.

Palabras-clave: irrigación, distribución Gaussiana, jardín de casa, radiación solar.

1 INTRODUCTION

The maintenance of life on our planet is directly linked to water, but its intensive use in both urban areas and productive activities in the countryside has harmed the places where it is taken from in usable conditions (Rebouças, 2003). Pollution is also another factor that often entails a certain cost for its treatment for human use.

Thinking about water economy in household or small-scale agricultural production, a device was assembled based on Melo's work (2016; 2017), which advocates for the lowest possible cost in its manufacturing and can serve for small-scale irrigation using the abundant energy from the sun without the need for electrical energy.

This is the automatic solar irrigator, which uses attached siphons (Streeter; Wylie, 1975) that release water through controlled and economical dripping in small vegetable gardens with different crop productions or gardens. Related works on this topic can be seen in (Alvarenga; Ferreira; Fortes, 2014; Andrade, 2018; Cremasco; Castro; Boso; Costa *et al.*, 2018; Da Silva; De Castro, 2019; De Oliveira, 2023; Medici *et al.*, 2010; Mosena *et al.*, 2017). These aim to offer a manufacturing guide in different ways for the solar irrigator, but this work focuses on the performance of the equipment made by Melo (2016; 2017) in a small beet garden.

The use of such a device is presented as a simple, inexpensive, and cost-effective alternative for irrigating small crop productions, such as beets, in addition to its function in reducing water waste.

According to Guimarães (2008), “the Gaussian distribution is one of the most commonly used probability distributions in statistical analysis, and one of the most frequently used is the one that employs Gaussian distribution models for temperature” (p. 92). The temperatures recorded during the research months follow a Gaussian distribution, and the probability of the irrigator reaching its highest gradient in a given month was determined, as a result of a greater amount of water supplied to the plants.

The beet species tested in this research is adapted to the temperature conditions of the region. However, according to Tatlioglu and Kaya (2004), “high temperatures significantly affected the sugar yield of beet cultivars” (p. 259). The species *Beta vulgaris* (common beet), for instance, can tolerate temperatures up to 32°C. Nevertheless, it is essential to remember that beet cultivation is influenced by numerous factors beyond temperature, such as humidity, light, nutrition, and irrigation that significantly affect production. Concerning irrigation, these vegetables require frequent watering, and the soil should always be moist without waterlogging, as this type of crop is sensitive to soil water deficiency.

In 2015, a study conducted by de Almeida *et al.*, investigated the effects of water deficit on beet quality. According to the study, “beet plants were subjected to three levels of water deficit: daily irrigation (control), irrigation every three days, and irrigation every six days” (p. 36). The study concluded that water deficiency resulted in a significant decrease in beet sugar content, as well as an increase in acidity. The authors also noted

that water deficiency negatively affected the appearance and size of the beet, suggesting that water shortage may have a significant impact on the commercial production of the crop (De Almeida *et al.*, 2015, p. 36).

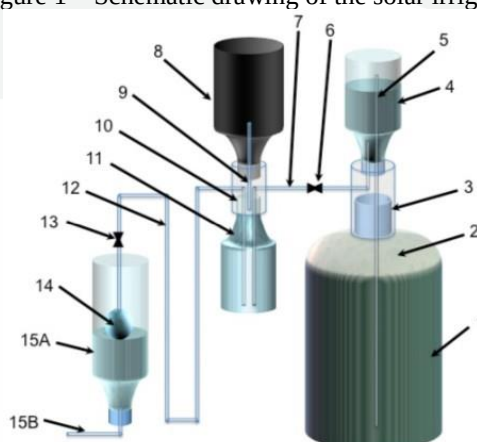
Thus, the aim of this article was to evaluate in which month the solar irrigator had the best performance, knowing that its effective operation occurred around 28°C, considering the value of monthly average and variance of maximum temperatures. This evaluation relates to the amount of water delivered and also to the number of beet plants produced during the months.

2 METHODOLOGY

2.1 THE SOLAR IRRIGATOR

The role of the solar irrigator is to provide controlled water supply according to the variation of ambient temperature. Recyclable materials such as Polyethylene terephthalate (PET) bottles, glass bottles, rubber tubes, electrical wire insulation, generally discarded materials, can be used in its assembly, which have potential to pollute the environment, but here serve as raw materials for the practical and economical application of the device.

Figure 1 – Schematic drawing of the solar irrigator.



Source: Melo (2016).

Table 1 provides a description of each number and its respective names, which identify the parts that are necessary for the construction of the irrigator. The complete assembly process can be found in (Melo, 2016; 2017).

Table 1 – Description of solar irrigator parts.

Number	Name
1	Primary container
2	Coupling funnel to container (1)
3	Coupler of containers (1) and (4)
4	Secondary container
5	Suction duct
6	Valve
7	Feeder duct
8	Pressurizer or solar pump
9	Hot air exhaust pipe
10	Coupler of containers (8) and (11)
11	Output containers
12	Dripper duct or double siphon
13	Siphon outlet valve (11)
14	Float
15A	Collector bottle (distributor)
15B	Outlet duct

Source: Melo (2016).

The operation of the solar irrigator is related to the physical process called *Thermohydrodynamics*, since water propulsion occurs through heating the air from a given container to the siphon, (Lima, 2016; Streeter, Wylie, 1975). The process occurs through siphons that are activated by the pressure of the heated air. In Figure 1, the black-painted bottle, upon receiving solar radiation, undergoes heating, which in turn transmits heat to the air inside it. The heated air expands and exerts pressure inside the bottle. Tube (9) allows the passage of hot air, pushing the water from inside container (11). The propelled water tends to flow through ducts (7) and (12). Through duct (7), water goes to the bottle (4) and stays trapped, while through duct (12), water reaches the outlet in the form of drops or flow, as shown in Figure 2 of the already constructed solar irrigator.

Figure 2 – Assembled solar irrigator.



Source: Dias, A. C. L. (2024).

2.2 GAUSSIAN DISTRIBUTION

In general, the Gaussian distribution is the most important in probability theory. The random variable X is understood as a number of components, with the distribution tending to a normal distribution as the number becomes very large.

The probability density is defined by

$$f_x(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left(\frac{1}{2}\right)\left[\frac{(x-\mu)}{\sigma}\right]^2}, \quad (1)$$

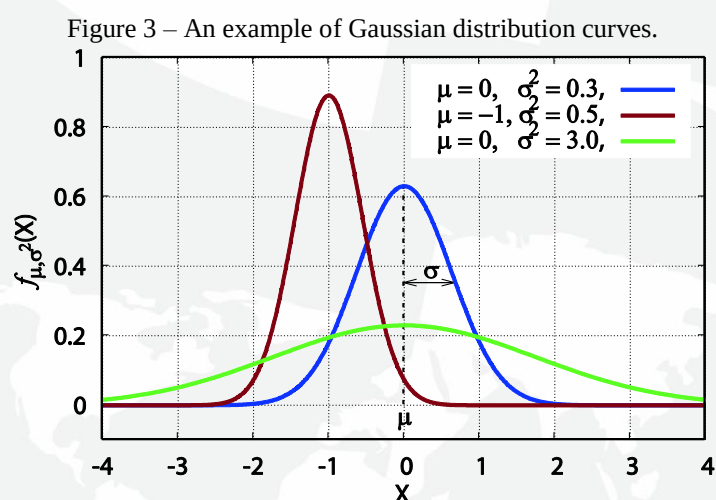
with:

μ being the mean or expected value and σ^2 the variance. The expected value μ of a random variable X that follows the Gaussian model can take any value between $-\infty < \mu < \infty$. The variance of a random variable X can only have values above zero, that is $\sigma^2 > 0$. μ and σ^2 are parameters of the Gaussian model.

The normal distribution, also known as the Gaussian distribution, has many applications and is widely used to approximate the distribution of continuous values that

exhibit a very particular behavior when we visualize the frequency distribution of their values, such as the temperatures during the hours of the day, which is one of the objectives of this work. Therefore, we must ensure that the probability values are determined with great accuracy.

The Gaussian curve or *Normal curve* depends only on the parameters μ and σ^2 , graphically represented according to Figure 3.



Source: Dias, A. C. L. (2024). Self-elaboration.

In this work, the random variable X refers to temperature values T and frequency density a , $f_T(t)$, Equation 2.

$$f_T(t) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\left(\frac{1}{2}\right)\left[\frac{(t-\mu)}{\sigma}\right]^2}. \quad (2)$$

The direct calculation of probabilities requires advanced mathematics, however the problem can be easily circumvented by using Equation 3, where the random variable T with a normal distribution, mean μ and standard deviation σ is considered.

$$Z = \frac{t - \mu}{\sigma}, \quad (3)$$

which

Is called the standard normal distribution, in other words, it has a normal distribution with mean 0 and variance 1.

Since temperature values are random and continuous, the Gaussian stochastic process provides more accurate responses in terms of probability distributions for this type of research.

2.3 VEGETABLE USED IN THE RESEARCH

The research site is part of a region in the state of Pará, with a humid equatorial climate, high temperatures, and high humidity throughout the year. Therefore, it is possible to plant beets, a type of vegetable that belongs to the Amaranthaceae family, year-round in the region, as long as the temperature and humidity conditions are suitable for plant growth.

Nevertheless, it is important to avoid the rainiest period, which occurs between December and March, as excessive moisture can harm the development of tuberous roots and favor the emergence of diseases. Therefore, it is recommended to plant beets in this region during the dry season, which runs from April to November. During this period, temperatures are milder and humidity is lower, providing favorable conditions for cultivating this vegetable. However, it is relevant to check the local climate and soil conditions, as well as the availability of water for irrigation, before planting.

Thus, the average time for beets to mature depends on several factors, such as the vegetable variety, growth conditions, and climate. In general, they take 60 to 90 days to mature after sowing (Bhering, 2019, p. 563; Sanches, 2014, p. 149). This period of time is widely accepted in the scientific literature as an average estimate for beet cultivation time.

Beets can be harvested when they reach the desired size, usually around 7 to 10 centimeters in diameter. It is important to harvest these tubers before they become too large or too mature, because that can negatively affect their taste and texture.

In addition, it is important to observe signs of maturity in beets, such as the color of the leaves. When the leaves begin to wilt and turn yellow, it is a sign that these vegetables are almost ready for harvest. Therefore, it is recommended to harvest them before the leaves wilt completely, because beets can lose quality and flavor if left in the ground for too long.

During the last years, with genetic improvement, cultivars more adapted to high temperatures have been created, providing conditions for year-round cultivation and for regions with more severe climates. The beet species used in the research is called Itapuã 202, developed by Embrapa to better adapt to the climatic and soil conditions of the North region of Brazil, including the state of Pará.

The ideal temperature for the beet variety Itapuã 202 will depend on various factors, including the growth phase of the plant and the overall environmental conditions. However, in general, the beet prefers cooler temperatures, between 18 and 24°C.

To avoid the destruction of the inflorescence, which is the set of flowers on a particular branch, it is important to avoid extreme temperatures. Very low temperatures, below 10°C, can harm the plant's development, while very high temperatures, above 30°C, can cause the abortion of flowers or the formation of seeds with low viability.

According to Fernandes *et al.* (2003), the beet cultivar Itapuã 202 presents good adaptation to high temperatures and can withstand up to 30°C without significantly compromising its development. Therefore, the ideal temperature range for the beet Itapuã 202 to avoid inflorescence destruction varies between 18 and 30°C. However, it is important to observe the specific cultivation conditions and monitor the plant regularly to ensure it is developing properly.

2.4 MATERIALS AND METHODS

The tests with the solar irrigator were carried out during the months of March, April, May, and June of the year 2022. The months were chosen in this way because the beetroot crop takes around 60 to 90 days to mature and basically comprises only the autumn season, since the research begins at the end of summer, in the month of March, and ends in the beginning of winter, at the end of June.

The area chosen for the tests is located 17 km from the municipality of Abaetetuba - PA, on the PA 252 RD 151 km 17 highway, in Cupuaçu village, on a site created for vegetable planting. The area has dimensions of 1.2 m in length by 1.0 m in width, and the cultivars sown there were spaced at 0.2 m x 0.2 m, with the solar irrigator positioned as shown in Figure 4. According to the information about the area and its dimensions, 20 beetroot plants were sown, however, for illustrative purposes, only nine holes were displayed.

Figure 4 – The solar irrigator and the arrangement of holes to receive the beetroot seeds.



Source: Dias, A. C. L. (2024). Self-elaboration.

The maximum and minimum temperature data from the location were taken from the database of the National Institute of Meteorology (2022), which can be accessed at: (<https://portal.inmet.gov.br/paginas/catalogoaut#>). Of the temperatures, only the first 30

days of each month were used, all in order to facilitate the treatment of the information, the 31st day of the months of March and May, for example, were discarded.

The study aimed to evaluate in which month the irrigator had the best performance, given that its effective operation occurred around 28°C. The air inside the dark bottle needs to be heated in order to do work and propel the water out of the drip containers. Based on this information, its performance resulting from the temperature variation was compared with the amount of water expended and the beetroot production in the months.

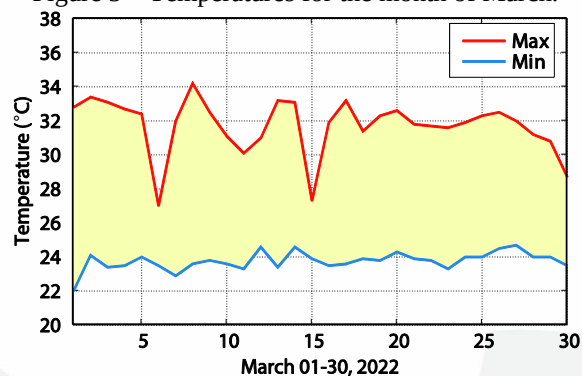
3 RESULTS AND DISCUSSIONS

This item was divided into two parts, namely: the first presents the minimum and maximum temperature values for each of the months, and the second displays the probability densities for a certain temperature range, checking the best performance values of the solar irrigator with a comparison between probability densities, indicating the month with the best performance of the irrigator with the amount of water expended and the production of beet crops.

3.1 TEMPERATURE VARIATIONS IN THE RESEARCH AREA

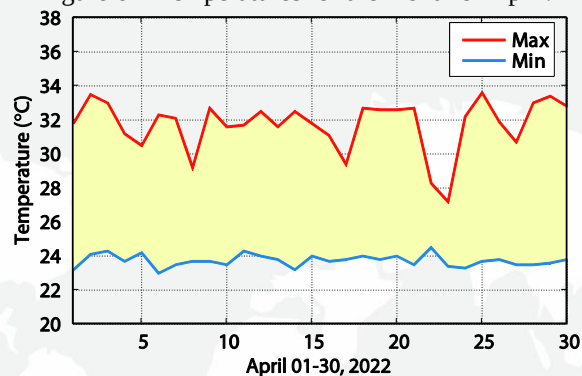
Figures 5, 6, 7 and 8 show the maximum and minimum temperature values, respectively, for the months of March, April, May, and June.

Figure 5 – Temperatures for the month of March.



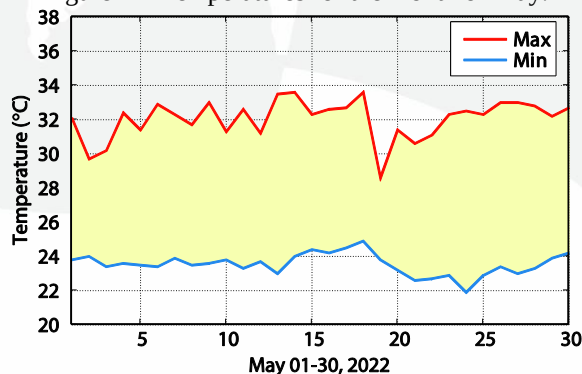
Source: Dias, A. C. L. (2024). Self-elaboration.

Figure 6 – Temperatures for the month of April.

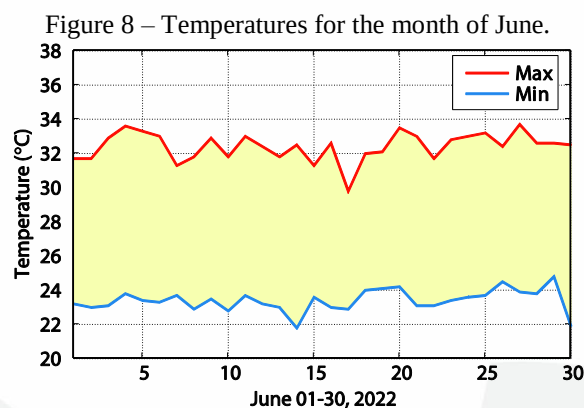


Source: Dias, A. C. L. (2024). Self-elaboration.

Figure 7 – Temperatures for the month of May.



Source: Dias, A. C. L. (2024). Self-elaboration.



Source: Dias, A. C. L. (2024). Self-elaboration.

From Figures 5, 6, 7, and 8, we observe that the behavior of the minimum and maximum temperatures is reasonably extreme, varying by around 4°C between them on different days. The average temperatures for each month are around 27.8°C. These temperature averages are ideal for the functioning of the solar irrigator, as previously mentioned its effective operation occurs around a temperature of 28°C, and above this temperature, it provides more water to the crop, enhancing its performance.

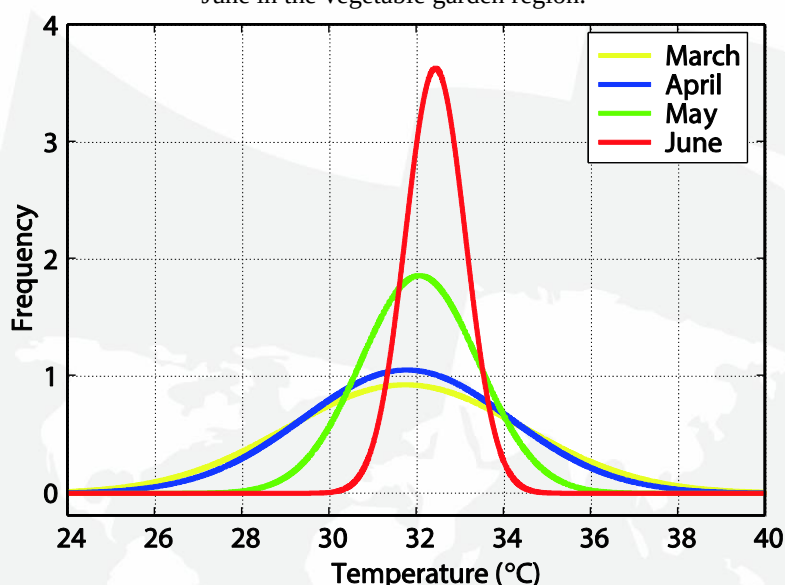
The month of March in this region of the country falls between two seasons, the end of summer and the beginning of autumn, with relatively high temperatures but not too low. The months of April and May also follow this trend with the autumn season. The month of June has a few days with relatively “low” temperatures of milder weather, but with very high temperatures compared to the other months selected in the research, as shown in Figure 8. They have relatively “high” temperatures throughout the month, reaching over 33°C on some days, showing a correlation with the lower temperatures that are higher compared to the low temperatures of the other months selected in the research. These large temperature variations, considering the average temperatures for the months, substantially affected the performance of the solar irrigator.

3.2 PERFORMANCE OF THE IRRIGATOR VERSUS WATER EXPENDED CROP PRODUCTION

Figure 9 shows the probability distribution regarding the means and variances of maximum temperatures for the months of March, April, May, and June. We did not

compile probability distribution data for minimum temperatures since the means for these temperatures in all months did not reach the ideal temperature for the solar irrigator's operation. Thus, the analysis for the research development would be unfeasible, and we would not have a basis for the discussions.

Figure 9 – Probability distribution of maximum temperatures for the months of March, April, May, and June in the vegetable garden region.



Source: Dias, A. C. L. (2024). Self-elaboration.

To analyze the irrigator's performance, we determined the probabilities in two situations, namely: the first where temperatures were above 30°C since it was important to analyze these probabilities, as above this value, beetroot production could be compromised by not forming the inflorescence, leading to abortion of flowers or the formation of seeds with low viability. Therefore, production would not be significant. The second, where temperatures were between 27°C and 30°C, was also important to analyze, as the solar irrigator's performance was fixed around 28°C. Moreover, the mean temperatures of the months were close to the value of 27.8°C, as shown in Table 2.

Table 2 – Probability values in (%) for temperatures between 27 and 30°C and above 30°C for the months of March, April, May, and June.

Months	P($t > 30$)	P($27 < t < 30$)
March	73,87	22,13
April	77,01	20,73
May	93,64	6,35
June	99,98	0,01

Source: Dias, A. C. L. (2024).

In Table 2, the probability values for the four months are presented. It can be observed that in the month of June, the probability of having temperatures above 30°C was approximately 100%, and between 27°C and 30°C, around 0.01%, indicating that the solar irrigator's operation was limited to temperatures above 30°C. This can make more sense by looking at Figure 9, where for an average of approximately 32°C, there is a frequency of temperatures around 4 values, in addition to a small variance relative to the mean, and in Table 3, where the amount of water delivered was much higher than the months of March and April, which, for example, had lower water delivery among all the months studied, due to the lower frequencies of high temperatures. On the other hand, it was found that the months of March and April had good beetroot production, with 16 out of a total of 20 plants.

Table 3 – Data collected during the research months.

Months	Irrigator performance	Quantity of delivered water (in liters)	Performance versus production	Production in (feet)
March	Good	542	Excellent	16
April	Good	639	Excellent	
May	Very good	1053	Fair	9
June	Excellent	1926	Fair	

Source: Dias, A. C. L. (2024).

Therefore, for the months of March and April, the irrigator was considered to have a good performance, since they expended little water and produced very well compared to the other months, Table 3. We believe that the solar irrigator heated up discreetly compared to June, for example, to the point of not providing much water, however, it became relatively sufficient for the cultivar feet to grow adequately.

For the month of June, according to Table 2, it provided the most temperature and water for the crops through the solar irrigator. We observed that the probabilities of having temperatures above 30°C were approximately 100%, and between 27°C and 30°C,

about 0.01%, indicating that the solar irrigator, during its operating time, practically operated with temperatures above 30°C and worked effectively, a little above its optimal operating temperature of 28°C.

In Figure 9, it is possible to observe that the average temperature for the month of June was around 32.2°C, with low dispersion when compared to other months. Table 3 shows that the irrigator provided a significant amount of water compared to March, for example. In terms of operation, the irrigator was excellent, but in terms of production, it had the worst rating compared to May. We believe that despite the significant amount of water delivered by the irrigator due to the high temperatures, which can potentially enhance its operation, the production was unsatisfactory, with only 9 out of 20 plants producing. It is worth noting that the amount of water delivered by the irrigator during high temperatures may be affected by simple evaporation. Additionally, the maturation of the cultivars at these temperatures was impaired due to the deficient formation of the inflorescence (Fernandes *et al.*, 2003).

Therefore, for the month of June, the irrigator was considered to have an excellent performance, as it provided a significant amount of water compared to the other months. However, comparatively, the production was not as good in this month. We believe that the solar irrigator heated up to the point of providing a lot of water, but it was insufficient for the beet plants to grow adequately. It is essential to emphasize that the amount of water required for drip irrigation in a small vegetable garden may vary depending on several factors, such as the size of the garden, soil type, plant species, among others.

The month of April, as shown in Table 2, was different from the other months, with a chance of approximately 77% of temperatures being above 30°C and around 20% within the range of 27°C to 30°C. This shows that the irrigator worked satisfactorily for the two temperature ranges considered in the study. This can be verified with an average temperature of 31.5°C and a considerable variance of around 2.8°C, as shown in Figure 9.

Table 3 shows that the amount of water delivered by the solar irrigator was approximately one-sixth more than in March, and the production was rated as the best alongside this month, compared to May and June, with 16 out of a total of 20 beet plants.

Therefore, for the month of April, the irrigator was considered to have excellent

performance, as it provided relatively a little more water compared to March and performed very well alongside it, as shown in Table 3. The solar irrigator heated up ideally for its proper functioning to the point of providing approximately 1/6 more water than the month with the least waste (March), becoming excellent in its well-balanced functioning and with a considerable production.

4 CONCLUSIONS

A Description of the solar irrigator was made with the intention of providing an alternative for water waste in small vegetable productions, especially using solar energy without the use of electric power. Its performance was enhanced in June, modest in March, and balanced in April. In the other months, we did not have significant changes in the Gaussian distribution of temperature.

Therefore, we conclude that the performance of the solar irrigator is not a determining factor in the production of this type of crop under the conditions of this study, although it spent a lot of water in June, it did not produce enough compared to March and April, which provided approximately half the amount of water and produced more than half of the cultivars.

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