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# Assessment of Water requirements for Horticultural Crops in Arid Regions

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## Abstract

Arid regions have very low precipitation values (usually less than 250mm), consequently there is little water availability, so in these regions efficient management of this resource is imperative. This study aims to assess the water needs of some horticultural crops and a fruit tree on the island of São Nicolau, Cape Verde. Twelve crops were selected among the most used by farmers in the area and three scenarios related to precipitation were created. The water needs of the crops in the three scenarios were assessed using the previously calibrated Hargreaves - Samani method. The water balance to determine irrigation consumption was made for the following 3 rainfall conditions: scenario 1 corresponds to the year with the lowest rainfall; scenario 2 is the average of the values recorded over the series; and scenario 3, the year with the highest rainfall. The consumption of water by the crops was not significantly different in the 3 scenarios, the difference being in the amount of water resulting from the precipitation that can be stored and, thus, determining which area can be dedicated to irrigated agriculture. The lettuce, cucumber, pepper and carrot cultures, since the cultures studied were those with the lowest water requirements. The cultivation of banana cultivation should be the subject of a study on its adaptability, due to its high consumption, namely the possibility of applying deficient irrigation in order to increase water productivity.

**Keywords:** Arid regions; Water needs; Horticultural crops

## Introduction

Arid climatic zones can be defined, according to [1], as those in which in no season of the year can crops grow without the use of irrigation, where, normally, the average annual precipitation is less than 250 mm and with a very irregular, unpredictable fall and with wide intervals.

In these regions, which normally have very high evaporation rates, as well as very high solar radiation values and very low air humidity, a very intensive type of agriculture could develop. However, normally, its low resources in surface or ground water prevent this from happening [2].

The need for water in a crop corresponds to the evaporative demand for that crop in a given environment and receiving specific cultural treatments. Crop evapotranspiration is the sum of crop transpiration and soil water evaporation. There are several methods that can be used to calculate the reference evapotranspiration, among which Penman-Monteith [3] stands out.

With this method, it is possible to obtain results similar to those observed in the measurement of grass cover evapotranspiration, as it has a solid physical base and for clearly incorporating both physiological and aerodynamic parameters. The grass was chosen as a reference crop, with a constant height and also a constant surface resistance, in order to avoid the problems of local calibration, which require exhaustive and expensive studies [3].

In many regions, in particular in Africa, there are no consistent climatic data and, often, only maximum and minimum temperatures are obtained. Under these conditions, it is not possible to use the Penman-Monteith method, so more simplified ones should be used, such as the Hargreaves-Samani method. This method is widely used for irrigation management in situations with little available meteorological data [4]. According to Shahidian et. al, [5]. The Hargreaves-Samani equation has been used a lot by other authors and in several regions and with good results namely:

a) Sepahskhah and Razzaghi (2009) where they used lysimeters to compare the Thornthwaite, Willmott and Hargreaves- Samani equations in the regions semiarid regions of Iran and concluded that the calibrated Hargreaves-Samani equation was the most accurate.

b) Lopes Urra et al. (2006), compared seven $ET_0$ equations in the arid region of southern Spain with data from lysimeters and concluded that Hargreaves Samani was the second best after the Penman Montheith equation.

c) (Martínez-Cob and Tejero-Juste, 2004, Jensen et al., 1997), and as the Hargreaves equation does not account for the wind, it differs significantly from calculations performed with the Penman-Monteith equation. As the wind speed in the greenhouse is negligible, it is likely that these equations can produce more satisfactory results inside greenhouses than outside.

The present work uses the Hargreaves-Samani method for the hydrographic basin of Fajã, in the municipality of Ribeira Brava, on the island of São Nicolau, in Cape Verde.

## Methodology

The island of São Nicolau is located between the parallels 16º 30 'and 16º 40' N and the meridians 24º and 24º 30 'W. The NW is the island of Santa Luzia and the N-NE is the island of Sal. fifth island of the archipelago in surface, occupying an area of 343 km$^2$ with a maximum length of 45 km in the EW direction and a maximum width of about 25 km in the NS direction (Nunes, 1962a).

The Fajã River Basin is located in the municipality of Ribeira Brava and is one of the most important basins on the island of São Nicolau, extending from the Monte Gordo massif to the seafront, covering an area of 13.8 km$^2$, as shown shown in Figure 1.


**Figure 1:** Location of the study area, Fajã de Baixo. Source: Google Earth.

For the development of this study, the first selection of agricultural crops usually practiced by farmers in the Fajã area was carried out.

Within the range available, 12 representative crops were chosen, and which were considered most suitable for the economic sustainability of farmers in the irrigation perimeter. Eleven vegetables were selected, which are: onion, carrot, lettuce, cucumber, tomato, watermelon, sweet potato, pepper, beet, common potato and cabbage and a fruit tree, banana.

The assessment of the water needs of the crops was carried out based on the calculation of the reference evapotranspiration, for the average year, using the Hargreaves-Samani method, with the maximum temperature and minimum monthly temperature data for the Preguiça aerodrome station, for the period from 1941 to 1960 (19 years). These data were taken from the study and project to use the areas of influence of the new dams in Cape Verde, as there are no other data available [6].

The Hargreaves-Samani method was previously calibrated for the Cape Verde situations, based on the climate data of the island of Santiago, obtained from the PhD dissertation by Moreno [7].

In 1985 Hargreaves and Samani developed a simple equation that only needs air temperature data (minimum highs), and the latitude-dependent coefficients of the place and time of year. This equation, known as the Hargreaves-Samani equation, is described by the following expression:

$$ET_o = 0,0135 \text{ x } Krs\sqrt{(T\max - T\min)} \text{ x } Ra \text{ x}((\frac{T\min + T\max}{2}) + 17,8)$$

In which:

$ET_0$ = Reference evapotranspiration (mm / day)

Ra = radiation at the top of the atmosphere (mm / day)

Tmax = maximum temperature (ºC)

Tmin = Minimum temperature (ºC)

Krs is the equivalent unit of water evaporation, varying between 0.19 in coastal areas and 0.16 in inland areas. Usually the equation is written with Krs equal to 0.17

For this calibration, the reference evapotranspiration was calculated by the Penman-Monteith method and by the Hargreaves-Samani method, to then draw a calibration line that allows to adjust the results obtained by this last method. This line is described by the following equation:

$$Y = 1,4615x - 0,7662, \text{ com } R^2 = 0,99$$

Since Y, the result obtained by the Penman Montheith method and x, the result obtained by the Hargreaves-Samani method, the adjustment of the calibration line can be seen in Figure 2.


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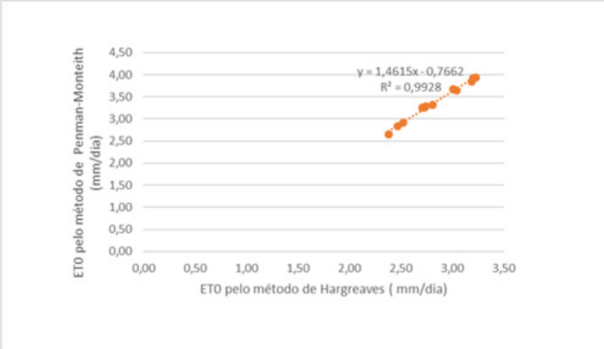


**Figure 2:** Adjustment of the calibration line of the Hargreaves -Samani equation for Cape Verde.

Cultural evapotranspiration (ETC) was obtained using the following formula ETC = $ET_0 * K_c$ where,

($ET_0$) is reference evapotranspiration

($K_c$) the cultural coefficient

The values of the cultural coefficients used were obtained using the specialized bibliography. The $K_c$ values and the respective references can be found in Table 1.

**Table 1:** Selected crops with the respective cycle durations, cultural coefficients for the development phases and durations of the development phases.

| Culture | Duration Cycle (days) | Initial Phase | | Intermediate Phase | | Final phase | | Source |
|---|---|---|---|---|---|---|---|---|
| | | *Kc* | Duration (days) | *Kc* | Duration (days) | *Kc* | Duration (days) | |
| Carrot (h= 0,35m) | 118 | 0,65 | 22 | 1,00 | 74 | 0,80 | 22 | Moreno, 2013 [7] |
| Lettuce | 75-140 | 0,70 | 20-35 | 1,00 | 45-95 | 0,95 | 10 | Almeida 2006 [9] |
| Beet | 70-90 | 0,50 | 15-25 | 1,05 | 45-55 | 0,95 | 10 | Almeida, 2006 [9] |
| Cucumber | 105-130 | 0,60 | 20-25 | 1,00 | 70-85 | 0,75 | 15-20 | Almeida, 2006 [10] |
| Cabbage | 80-195 | 0,70 | 20-30 | 1,05 | 50-125 | 0,95 | 10-40 | Almeida, 2006 [9] |
| Melancia | 110 | 0,40 | 20 | 1,00 | 60 | 0,75 | 30 | Almeida, 2006 [10] |
| Potatoes | 105-145 | 0,50 | 25-30 | 1,15 | 60-85 | 0,75 | 20-30 | Almeida, 2006 [10] |
| Onion (h= 0,30) | 201 | 0,60 | 23 | 1,04 | 150 | 0,40 | 28 | Moreno, 2013 [7] |
| Tomato (h= 0,45 | 144 | 0,60 | 30 | 1,18 | 84 | 0,80 | 30 | Moreno, 2013 [7] |
| Sweet potato (h =0,30) | 138 | 0,60 | 21 | 1,10 | 96 | 0,60 | 21 | Moreno, 2013 [7] |
| Bell pepper (h = 0,40) | 140 | 0,60 | 21 | 1,06 | 68 | 0,89 | 51 | Moreno, 2013 [7] |
| Banana 1 ano (h = 2,20 m) | 352 | 0,50 | 120 | 1,15 | 184 | 1,01 | 48 | Moreno, 2013 [7] |

Irrigation needs were calculated using the water balance method as described in [8], with three precipitation scenarios having been created, since in Cape Verde, rainfall varies greatly from year to year [9-11].

The balance was made for the following three rainfall conditions: scenario 1 corresponds to the year with the lowest rainfall; scenario 2 is the average of the values recorded over the series; and scenario 3, the year with the highest rainfall. Table 2 shows the precipitation values for the 3 scenarios.

**Table 2:** Precipitation (mm) in each scenario.

| | Jan | Feb | Mar | Apl | May | Jun | Jul | Aug | Sep | Out | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cenário 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,3 | 0 | 0 | 37,9 | 0 | 41,2 |
| Cenário 2 | 5 | 2,2 | 1,1 | 1,5 | 0,1 | 0,5 | 9,7 | 63,3 | 97,9 | 45,1 | 6,9 | 7,3 | 240,6 |
| Cenário 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 106,7 | 586,8 | 109 | 0 | 0 | 802,5 |


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## Results and discussion

The Hargreaves-Samani method underestimated the reference evapotranspiration values by 15-18% compared to the values obtained by the Penman-Monteith method.

The average annual reference evapotranspiration is 1737.6 mm. There is a certain difference from month to month, especially between the months of December and September, the difference between these two months being 102 mm. December was the lowest (96 mm) and September the highest (198 mm). If this difference is not taken into account, this fact can be problematic in terms of irrigated agriculture for an arid region in dry years, especially with regard to the availability of water to satisfy the water needs of the crop.

**Table 3:** Reference evapotranspiration (ET0), cultural coefficient (kc) and cultural evapotranspiration (ETc), related to different cultures.

| | | | Jan | Feb | Mar | Apl | May | Jun | Jul | Aug | Sep | Out | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***$ET_0$ (mm)*** | | | 101 | 114 | 145 | 162 | 156 | 160 | 155 | 157 | 198 | 184 | 110 | 96 |
| **Cultures** | **Banana** | $K_c$ | 1,15 | 1,15 | 1,15 | 1,15 | 1,15 | 1,15 | 1,01 | 1,01 | 0,5 | 0,5 | 0,5 | 0,5 |
| | | $ET_c$ | 116 | 131 | 167 | 186 | 179 | 184 | 157 | 159 | 99 | 92 | 55 | 48 |
| | **Onion** | $K_c$ | 1,04 | 1,04 | 1,04 | 1,04 | 1,04 | 0,4 | ### | ### | ### | ### | ### | 0,6 |
| | | $ET_c$ | 105 | 119 | 151 | 168 | 162 | 64 | ### | ### | ### | ### | ### | 58 |
| | **Cucumber** | $K_c$ | 1 | 0,75 | #### | ### | ### | ### | ### | ### | ### | ## | 0,6 | 1 |
| | | $ET_c$ | 101 | 86 | #### | ### | ### | ### | ### | ### | ### | ## | 66 | 96 |
| | **Beet** | $K_c$ | 1,05 | 0,95 | #### | ### | ### | ### | ### | ### | ### | ### | 0,7 | 1,05 |
| | | $ET_c$ | 106 | 108 | #### | ### | ### | ### | ### | ### | ### | ### | 77 | 101 |
| | **Cabbage** | $K_c$ | 1,05 | 0,95 | #### | ### | ### | ### | ### | ### | ### | ### | 0,7 | 1,05 |
| | | $ET_c$ | 106 | 108 | #### | ### | ### | ### | ### | ### | ### | ### | 77 | 101 |
| | **Potato** | $K_c$ | 1,06 | 0,89 | #### | ### | ### | ### | ### | ### | ### | ### | 0,6 | 1,06 |
| | | $ET_c$ | 107 | 101 | #### | ### | ### | ### | ### | ### | ### | ### | 66 | 102 |
| | **Carrot** | $K_c$ | 1 | 0,8 | #### | ### | ### | ### | ### | ### | ### | ### | 0,65 | 1 |
| | | $ET_c$ | 101 | 91,2 | #### | ### | ### | ### | ### | ### | ### | ### | 71,5 | 96 |
| | **Lettuce** | $K_c$ | 1 | 0,95 | #### | ### | ### | ### | ### | ### | ### | ### | 0,7 | 1 |
| | | $ET_c$ | 101 | 108 | #### | ### | ### | ### | ### | ### | ### | ### | 77 | 96 |
| | **Tomato** | $K_c$ | ### | ### | 0,6 | 1,18 | 1,18 | 0,8 | ### | ### | ### | ### | ### | ### |
| | | $ET_c$ | ### | ### | 87 | 191 | 184 | 128 | ### | ### | ### | ### | ### | ### |
| | **Sweet potato** | $K_c$ | ### | ### | 0,6 | 1,1 | 1,1 | 0,6 | ### | ### | ### | ### | ### | ### |
| | | $ET^c$ | ### | ### | 87 | 178 | 172 | 93 | ### | ### | ### | ### | ### | ### |
| | **Bell pepper** | $K_c$ | ### | ### | 0,6 | 1,06 | 1,06 | 0,89 | ### | ### | ### | ### | ### | ### |
| | | $ET_c$ | ### | ### | 87 | 172 | 165 | 142 | ### | ### | ### | ### | ### | ### |
| | **Water-melon** | $K_c$ | ### | ### | 0,4 | 1 | 1 | 0,75 | ### | ### | ### | ### | ### | ### |
| | | $ET_c$ | ### | ### | 58 | 162 | 156 | 120 | ### | ### | ### | ### | ### | ### |

####: periods when the crop is not being grown.



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In other years, the high evaporative rate coincides with the months of greatest precipitation. Table 3 shows the average monthly values of reference evapotranspiration and cultural evapotranspiration for the cultures considered in this study.

In Figure 2, it can be seen that the banana crop is the one with the highest irrigation consumption, about 1100 mm over its cycle, which represents 57.6% of the annual reference evapotranspiration on the island of São Nicolau.

The crops with the least watering consumption are lettuce, peppers, carrots, cucumbers and cabbage. This aspect must be taken into account when choosing the crop, especially in cases where there is little availability of water for irrigation. On the other hand, the banana culture, being the crop that presents the highest consumption of irrigation, in situations of water scarcity should give way to other cultures that are less demanding in water, with the aim of a more sustainable management of water resources.

The irrigation needs and the respective amount must be taken into account when choosing the crops and the area to be devoted to each of these crops, especially in years with little water availability. On the other hand, from the market point of view, in which the price is often not competitive, especially for those who use surface irrigation, as the demand for water is greater in relation to that of drip irrigation. In scenario 2, despite presenting greater precipitation compared to scenario 1, with a difference of 199.4 mm, there is not much difference (27.9 mm) in terms of water consumption.

Regarding the irrigation needs for the selected crops, there are differences in terms of the monthly irrigation needs. The biggest difference is observed in the lettuce culture, without significant distinction between scenarios (which also happens with peppers) and with watering needs about five times lower than those of bananas and three times lower than those of onions as you can see in the Figure 3.

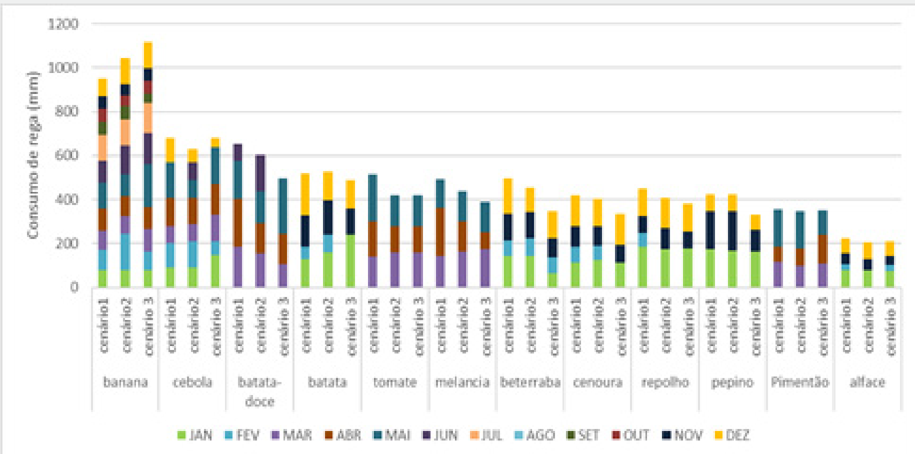


**Figure 3:** Evolution of irrigation consumption by scenario, month and crop.

## Evolution of irrigation consumption throughout the year

The months with the highest consumption of water for irrigation are the months of January and May, with around 1000 mm, with no difference for the 3 scenarios in the month of January (Figure 4). The same is no longer the case with the month of May, where the lowest consumption of irrigation water is recorded in scenario 2, with a consumption of 103.5 mm, as a result of a better distribution of rainfall throughout the year.

In the period from July to October there is practically no water consumption, particularly for scenarios 2 and 3. (Figure 4)

The evolution of water consumption by irrigation and the water needs of the crops throughout the year is very important information to adapt the crop calendar, so as not to install a water demanding crop in periods when there is a greater demand for water. water by the others, thus compromising the management of water resources.

## Conclusion

Access to climatic data for the calculation of evapotranspiration in Cape Verde, and in particular on the island of São Nicolau, is still limited because, in addition to the lack of weather stations, the few stations that exist operate in a deficient manner.

The evolution of water consumption by irrigation and the water needs of the crops throughout the year is very important information to adapt the crop calendar, so as not to install a water demanding crop in periods when there is a greater demand for water. water by the others, thus compromising the management of water resources.


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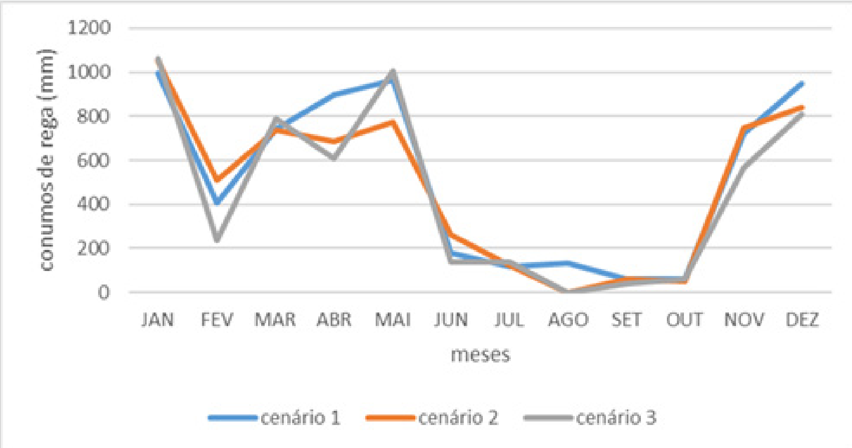


**Figure 4:** Irrigation water consumption throughout the year for the 3 scenarios considered.

In the irrigation perimeter of the Banca Furada dam, it can be seen that there will be two periods of the year with a greater number of crops on the ground and, consequently, greater area for irrigation and greater water consumption: from November to February and from March to June.

For some crops, namely the banana crop, higher water consumption was obtained in scenario 3 (the year with the highest rainfall) than in other scenarios, contrary to what was expected. This is due to the fact that the months of August, September and October present high values of precipitation, that is, great availability of water.

The consumption of water by the cultures was not significantly different in the 3 scenarios, the difference being the amount of water resulting from precipitation that can be stored and, thus, determining which area can be dedicated to irrigated agriculture.

The lettuce, cucumber, pepper and carrot cultures, since the cultures studied were those with the lowest water requirements.

The cultivation of banana cultivation in years with little rainfall should be the subject of a study on its adaptability, due to its high consumption, namely, the possibility of the application of deficient irrigation in order to increase the productivity of the water used in this culture.

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