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Determination Of The Water Needs Of The Cocoa CCN51 (Theobroma Cacao L.) Crop From Georeferenced Information In The Subtropics Of Ecuador

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Abstract

The study was conducted in the San Francisco de Chipe area, in the cantonal capital of La Maná (Ecuador), to carry out the agronomic design for implementing a sprinkler irrigation system in the cultivation of cocoa (Theobroma cacao L.) variety CCN51. It began with a topographic survey, soil analysis to determine the physical parameters for irrigation purposes and the analysis of historical meteorological data of monthly average temperature, relative humidity and precipitation recorded by the INAMHI M0124 San Juan station, with this information the agronomic design was carried out, which determined the following results: the total irrigated area corresponds to 1.28 hectares; the potential evapotranspiration (ETP) determined by the Hargreaves method is 2.99 mm/day; the crop evapotranspiration (ETc) is 3.14 mm/day; the water demand corresponds to the period from July to November where the month with the highest demand (September) was recorded, a value of 1.89 mm/day was obtained; an irrigation frequency of 5 days was determined, with an irrigation time of 2 hours to satisfy a total lamina of 12.58 mm, with a required water volume of 161.05 m3; the selected sprinkler operates with a flow rate of 0.21 l/s and an irrigation frame of 10 x 10 m; the effective irrigation day is 8 hours in which 4 irrigation sectors can be had and the irrigation time per sector is 2 hours.

Keywords: agronomic; temperature; humidity; evapotranspiration; lamina

Resumen

La presente investigación se llevó a cabo en el recinto San Francisco de Chipe, de la cabecera cantonal de La Maná (Ecuador), con el objetivo de realizar el diseño agronómico para la implementación de un sistema de riego por aspersión en el cultivo de cacao (Theobroma cacao L.) de variedad CCN51. Se inició con un levantamiento topográfico, el análisis de suelo para la determinación de parámetros físicos con fines de riego y el análisis de los datos meteorológicos históricos de temperatura media mensual, humedad relativa y precipitación registrados por la estación INAMHI M0124 San Juan, con esta información se realizó el diseño agronómico que determino los siguientes resultados: el área total de riego corresponde a 1.28 hectáreas; la evapotranspiración potencial (ETP) determinada por el método de Hargreaves es de 2.99 mm/día; la evapotranspiración de cultivo (ETc) es de 3.14 mm/día; la demanda hídrica corresponde al periodo desde el mes de julio a noviembre en donde se registró el mes con mayor demanda (septiembre), se obtuvo un valor de 1.89 mm/día; se determinó una frecuencia de riego de 5 días, con un tiempo de riego de 2 horas para satisfacer una lámina total de 12.58 mm, con un volumen de agua requerido de 161.05 m3; el aspersor seleccionado opera con un caudal de 0.21 l/s y un marco de riego de 10 x 10 m; la jornada efectiva de riego es de 8 horas en el que se pueden tener 4 sectores de riego y el tiempo de riego por sector es de 2 horas.

Palabras clave: agronómico; temperatura; humedad; evapotranspiración; lámina

Introduction

Cocoa (Theobroma cacao L.) is a traditional crop in the Ecuadorian Littoral with an important role in the economy, being one of the sources of foreign exchange for the country (INIAP, 2017). Ecuador has a planted area of 421221 hectares, of which 80% is in the hands of small and medium farmers (INIAP, 2017).

The main cocoa-producing province in the country is Los Rios, which has 28% of the area planted, Guayas 22% and Manabi 18%. In comparison, the province of Esmeraldas, with 7.5%, El Oro participates with 5%, Bolivar with 4.4%, Cotopaxi with 4% Santo Domingo with 3.6%, and the balance of 11.10% is distributed among the provinces of Azuay, Cañar, Chimborazo, Loja Zamora Chinchipe and Sucumbíos (INIAP, 2020).

Irrigation is an indispensable resource to ensure a good harvest, while lack of water negatively influences the number of pods, size of the pods and weight of the beans (seed rate decreases). A cocoa orchard needs more than 100 mm of water per month to meet its needs and fulfill its sprouting, flowering, fertilization and fruit growth processes. Therefore, during the 6-month dry season, irrigation cycles every 15 days can be recommended as a reference, establishing a total of 12 irrigation events, and applying approximately 60 mm of water per event (INIAP&GTZ, 2008).

Hence the need to research the cocoa crop's water requirements to implement technified irrigation systems that allow water irrigation to be supplied efficiently and in technically adequate quantities according to the crop type, land area, weather conditions and agro-technical needs.

Allowing the supply of water resources to meet the needs of producers and achieving responsible management of this resource without causing environmental impact, improving the agricultural conditions of the sector by obtaining a higher and better production.

Methodology

The present research work was carried out in San Francisco de Chipe, belonging to the cantonal capital of La Maná in the province of Cotopaxi, with a geographical location: Latitude 0º 54' 59" S; Longitude 79º 14' 44" W at an altitude of 215 meters above sea level.

The work consisted of determining the parameters to define the water requirements to provide sprinkler irrigation to an area of 1.28 hectares where cocoa of the CCN51 variety is grown. To obtain the water demand of the cocoa crop, the climatic factors of average monthly temperature, relative humidity and precipitation were analyzed. The meteorological reference station is INAMHI M0124 San Juan, located 6 km from the project area.

The agronomic design determined the maximum irrigation lamina, the frequency, irrigation time, the volume of water required, and the type of sprinkler to satisfy the crop's water needs in the months with irrigation demand.

Materials And Equipment

The materials and equipment used in this research are detailed in Table 1.

Table 1. *Materials and Equipment.*

Materials	Equipment
Hand tools	Computer
Auger	Camera
Tape measure	Total Station
Flexometer	GPS RTK
PVC pipe	Combustion centrifugal pump
PVC Accessories	Laboratory for physical soil samples
PVC cleaner	Pressure gauge
PVC glue	Sprinklers
Closing arc	
Flannels	

Prepared by: *(Tapia C, 2021)*

Soil physical parameters

The soil sample obtained was sent to the INIAP-Santa Catalina soil laboratory, where the following characteristics were evaluated: field capacity (CC); permanent wilting point (PMP); bulk density (Dap); gravimetric humidity (Hg); volumetric humidity (Hv); sand, silt and clay content; and textural class.

Research on agrometeorological parameters

For the present research, an analysis of the agrometeorological information was carried out, considering the following parameters: temperature, precipitation, cloud cover and wind speed in the database of the San Juan INAMHI M0124 meteorological station, considering a 48-year data series.

Determination of Potential Evapotranspiration (ETP)

The method proposed by Hargreaves was used to determine the Potential Evapotranspiration or reference Evapotranspiration, using the information on temperature and relative humidity (Nuñez, 2015).

Hargreaves' methodology proposes the following equation:
Hargreaves' formula

□□□ = □□ ∗ □□□ ∗ □□ ∗ □□

Where:
ETP = Potential Evapotranspiration (mm/month)
MF = Monthly latitude factor
TMF = Mean monthly temperature (ºF).
CH = Relative humidity correction factor
CE = Correction factor for the height or elevation of the site

Monthly latitude factor (MF)

According to the degrees of latitude for the site location, the monthly latitude factor was determined based on Table 2.

Table 2. *Monthly latitude factor.*

Lat Sur	MESES											
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
1	2.788	2.117	2.354	2.197	2.137	1.990	2.091	2.216	2.256	2.358	2.234	2.265
2	2.371	2.136	2.357	2.182	2.108	1.956	2.050	2.194	2.251	2.372	2.263	2.301
3	2.353	2.154	2.360	2.167	2.079	1.922	2.026	2.172	2.246	2.386	2.290	2.337
4	2.385	2.172	2.362	2.151	2.050	1.888	1.995	2.150	2.240	2.398	2.318	2.372
5	2.416	2.189	2.363	2.134	2.020	1.854	1.960	2.126	2.234	2.411	2.345	2.407
6	2.447	2.050	2.363	2.117	1.980	1.820	1.976	2.103	2.226	2.422	2.371	2.442
7	2.478	2.221	2.363	2.099	1.959	1.785	1.893	2.078	2.218	2.233	2.397	2.476
8	2.508	2.237	2.362	2.081	1.927	1.750	1.858	2.054	2.210	2.443	2.423	2.510
9	2.538	2.251	2.360	2.062	1.896	1.715	1.824	2.028	2.201	2.453	2.448	2.544
10	2.567	2.266	2.357	2.043	1.864	1.679	1.789	2.003	2.191	2.462	2.473	2.577
11	2.596	2.279	2.354	2.023	1.832	1.644	1.754	1.976	2.180	2.470	2.497	2.610
12	2.625	2.292	2.350	2.002	1.799	1.608	1.719	1.950	2.169	2.477	2.520	2.643
13	2.652	2.305	2.345	1.981	1.767	1.572	1.684	1.922	2.157	2.464	2.543	2.675
14	2.680	2.317	2.340	1.959	1.733	1.536	1.648	1.895	2.144	2.490	2.566	2.706
15	2.707	2.326	2.334	2.937	1.700	1.500	1.612	1.867	2.131	2.496	2.588	2.738
16	2.734	2.339	2.317	1.914	1.666	1.464	1.576	1.838	2.117	2.500	2.610	2.769
17	2.760	2.349	2.319	1.891	1.632	1.427	1.540	1.809	2.103	2.504	2.631	2.799
18	2.785	2.359	2.311	1.867	1.598	1.391	1.504	1.780	2.068	2.508	2.651	2.830
19	2.811	2.368	2.302	1.843	1.564	1.354	1.467	1.750	2.072	2.510	2.671	2.859

Source: *Vasquez (2017)*

Average monthly temperature (TMF)

Monthly average temperature data from the INAMHI M0124 meteorological station was used for a 48-year series. To determine the monthly TMF values, the monthly averages were expressed in degrees Fahrenheit.

Relative humidity correction factor (CH)

According to Vasquez (2017), the relative humidity correction factor is determined under the following conditions:

The following equation applies when the monthly average relative humidity (RH) value is higher than 64%.

If RH > 64 %.

$$CH = 0.166(100 - RH)^{\frac{1}{2}}$$

For RH values below 64%, a value of CH = 1 is adopted.

Correction factor for site height or elevation (EC)

The expression used is as follows:

$$CE = 1 + 0.04 * \frac{E}{2000}$$

Where:
CE = Correction factor for the height or elevation of the site
E = Altitude of the irrigation project

Obtaining the crop coefficient (kc)

To obtain the coefficient of the cocoa crop (*Theobroma cacao L.),* the "Guide for determining crop evapotranspiration" was used, established by (FAO56, 2006)

Crop evapotranspiration (ETC)

WWF. (2005). The calculation of crop evapotranspiration is based on the following relationship:

$$ETC = ETP * kc$$

Where:
ETP = Potential or Reference Evapotranspiration
kc = crop coefficient

Effective precipitation

Information on average monthly precipitation (P) from the INAMHI M0124 meteorological station was used for a 48-year series. To determine the adequate precipitation (Pe), the methodology proposed by "Soil Conservation Service Method" was used, which indicates that it can be obtained through the following:

Carrazón, J. (2007), For mean monthly precipitation values, P ≤ 250 mm/month

$$Pe = \frac{P * (125 - 0.2P)}{125}$$

If average monthly precipitation P > 250 mm/month

$$Pe = 125 + 0.1\,P$$

Parameters for the agronomic design of sprinkler irrigation.

Crop water demand (D)

The following equation determines water demand:

$$D = ETC - Pe$$

Where:

D = Water demand
ETC = Crop evapotranspiration
Pe = Effective precipitation

Usable sheet (La)

It is the water reserve contained in the soil in the root zone of the soil; for its determination, the following relation was used:

$$La = \frac{(CC - PMP)}{100} \times \frac{Dap}{Dw} \times Pr$$

Where:
The = Usable sheet
CC = Field capacity
PMP = Permanent wilting point
Dap = Bulk density
Dw = Density of water
Pr = Root depth

Net irrigation sheet (Ln)

The net irrigation lamina (Ln) considers the usable lamina (La) of the soil and the soil depletion fraction (fa), employing the following relationship:

$$Ln = La \times fa$$

Where:
Ln = Net irrigated net sheet
The = Usable sheet
fa = depletion fraction

The depletion fraction or irrigation threshold (fa), depends on the type of crop to be irrigated and was obtained from the methodology established by the (FAO56, 2006)

Maximum Irrigation Frequency (Frm)

It refers to the maximum interval between two successive irrigations; the following equation is used for its determination:

$$Frm = \frac{Ln}{D}$$

Where:
Fmr = Maximum Irrigation Frequency
Ln = Net irrigated net sheet
D = Water demand

Actual irrigation frequency (Fr)

To define the real irrigation frequency (Fr), the operation of weekly irrigation was considered and considering not to exceed the days calculated in the maximum irrigation frequency.

Adjusted net irrigated net sheet (Lnj)

It is necessary to adjust in order to determine the net irrigation laminar, considering the real irrigation frequency, which determination consists of the application of the following expression:

□□□ = □□ □ □

Where:
Lnj = Adjusted net irrigated net sheet irrigation
Fr = Actual irrigation frequency
D = Water demand

Gross irrigation film (Lb)

The gross irrigation lamina is determined as a function of the net irrigation lamina and the application efficiency of sprinkler irrigation. The following equation determined it:

□□ = □□□ / □□

Where:
Lb = Gross irrigated area
Lnj = Adjusted net irrigated net sheet irrigation
Ea = Application efficiency

Criteria for sprinkler selection

The following aspects or criteria were considered for sprinkler type selection: type; model; nozzle size; operating pressure; flow rate, and wetting diameter.

Spacing between sprinklers and laterals

According to Cadena (2012), the maximum spacing between sprinklers and laterals (Ea x El), according to the percentage of wet diameter, obeys Table 3.

Table 3. *Maximum spacing between sprinklers and laterals.*

Wind in Km/h	In Square (%)	In Rectangle (%)	In Triangle (%)
0 - 5	55	50 x 60	60
6 - 12	50	45 x 60	55
13 - 19	45	40 x 60	50

Source: *Cadena (2012)*

Irrigation frame (Mr)

Once the spacing between sprinklers and laterals has been defined, the following expression determines the irrigation frame:

□□ = □□ □ □□

Where:
Mr = Irrigation frame (m2)
Ea = Spacing between sprinklers (Ea)
El = Spacing between sides (El)

Rainfall or sprinkler application intensity (Pas)

The following formula determined the rainfall or sprinkler application intensity (Pas):

$$Pas = \frac{qa}{Mr}$$

Where:
Pas = Sprinkler rainfall (mm/h)
qa = sprinkler flow rate (l/h)
Mr = irrigation frame (m2)

Irrigation time (Tr)

The irrigation time considers the following expression for its determination:

$$Tr = \frac{Lb}{Pas}$$

Where:
Tr = irrigation time (h)
Lb = Gross sheet (Lb)
Pas = Sprinkler rainfall (mm/h)

Number of irrigation positions or zones (Np)

The number of irrigation sectors or zones was determined using the following equation:

$$Np = \frac{JER}{Tr}$$

Where:
Np = Number of irrigation positions or sectors
JER = Effective irrigation day (h)
Tr = irrigation time (h)

Area of irrigated areas (Zr)

According to the number of zones and the total area of the irrigation project, it is possible to determine the area of each irrigation zone using the following expression:

$$Zr = \frac{A}{Np}$$

Where:
Zr = Area of the irrigated area or sector (ha)
A = Area of the irrigation project (ha)
Np = Number of positions

Maximum number of sprinklers per sector (Nasp)

$$Nasp = \frac{Zr}{Mr}$$

Where:
Nasp = Maximum number of sprinklers
Zr = Area of the irrigated area or sector (ha)
Mr = irrigation frame (ha)

Flow per hectare (Qha)

$$Qha = Pas\left(\frac{10000}{3600}\right)$$

Where:
Qha = Flow per hectare (l/s)
Pas = Sprinkler rainfall (mm/h)

Results and discussion

Agronomic design.

Agrometeorological elements of the study area.

For the present work, mean monthly temperature, mean monthly relative humidity and mean monthly precipitation were analyzed.

An analysis was made of the existing information in the database of the National Institute of Meteorology and Hydrology (INAMHI), considering data from 48 years of records.

Average temperature

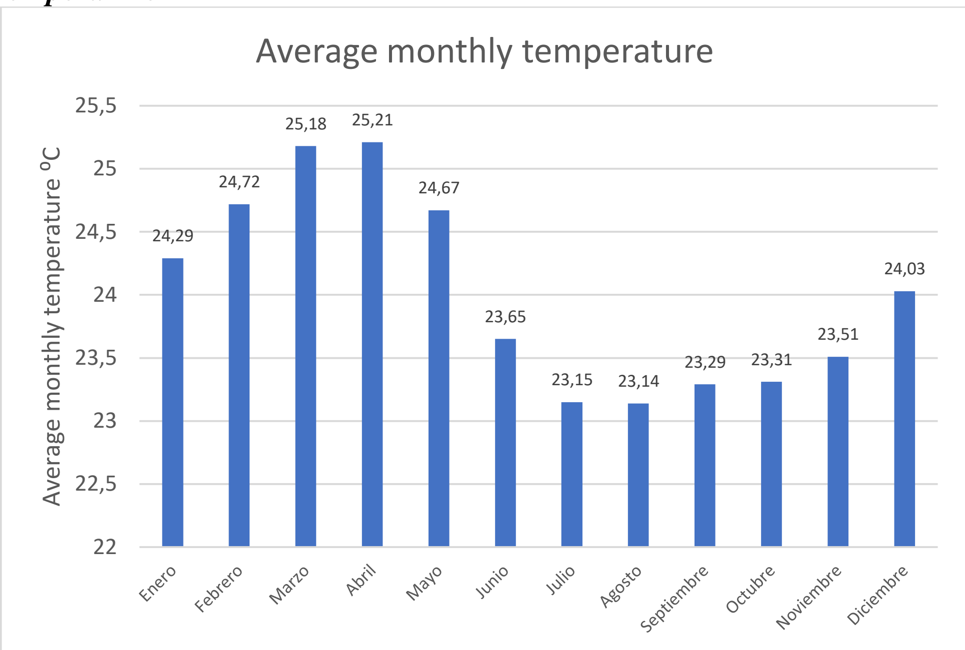

Figure 1. *Mean monthly temperature in 48 years.*
Source: *(INAMHI, 2019).*

The information shown in Figure 1 results from the analysis of meteorological information regarding the average monthly temperature recorded at the meteorological station MO124 San Juan La Maná during 48 years.

As shown in Figure 1, the monthly mean temperature ranges between 23 ºC and 25 ºC, and the highest monthly mean temperature data correspond to March and April with 25.18 ºC and 25.21 ºC, respectively. While the lowest corresponds to July and August with values of 23.15 ºC and 23.14 ºC.

Considering the information presented in Figure 1, which indicates the average monthly mean temperature for years, the annual mean temperature results in 24.01 ºC.

Relative Humidity

Atmospheric humidity is the presence of water vapor in the air resulting from evapotranspiration occurring at the earth's surface.

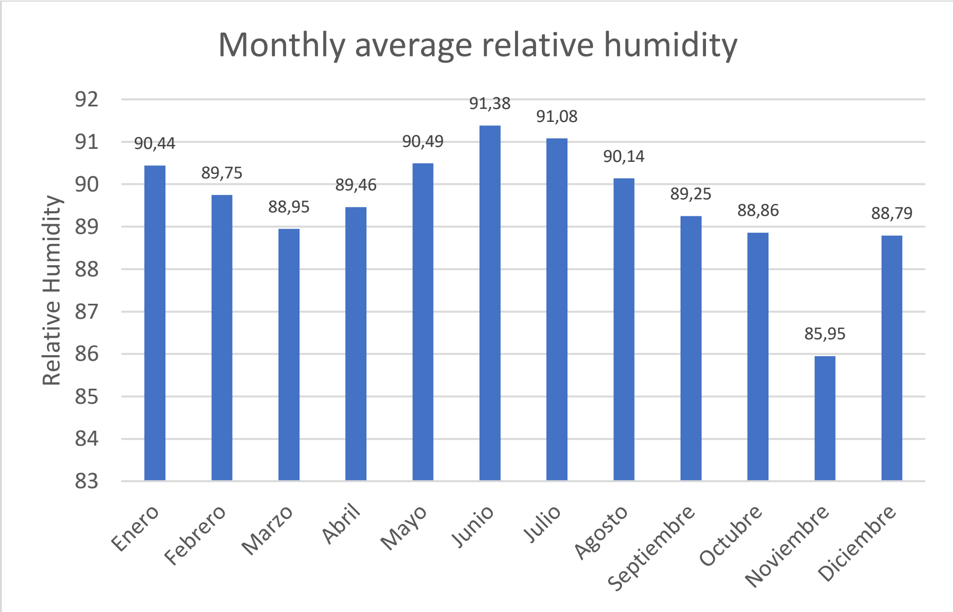

Figure 2. *Mean monthly relative humidity at weather station M0124.*
Source: *(INAMHI, 2019).*

From the information analyzed, it can be identified that there are high relative humidity values during June and July at 91.38% and 91.08%, while there are low values in October, November and December with 88.86%, 85.95% and 88.79%, respectively.

Considering the monthly relative humidity values, a value of 89.55% was obtained, corresponding to the average annual relative humidity in the area of influence of meteorological station M0124 San Juan.

Average monthly precipitation

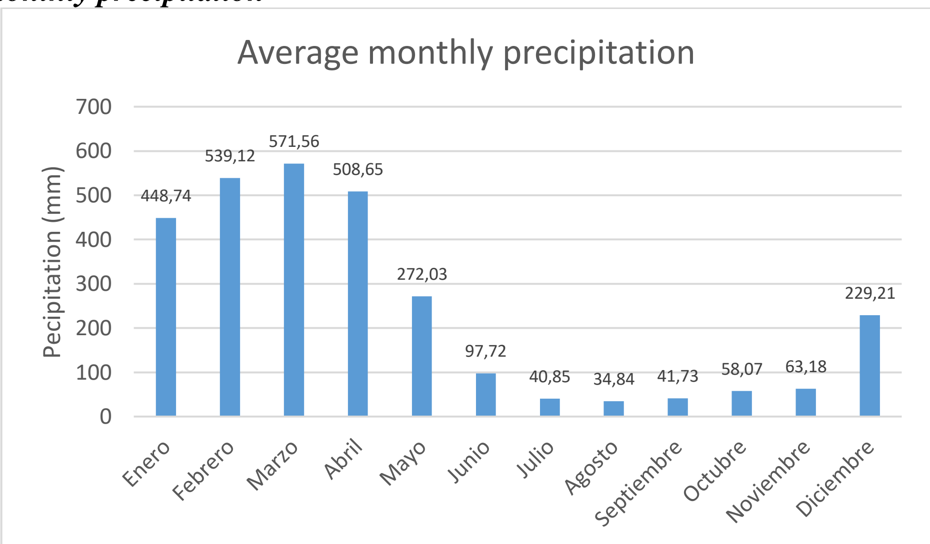

Figure 3. *Mean monthly precipitation at weather station M0124.*
Source: *(INAMHI, 2019).*

According to the information shown in Figure 4, the months of high, medium and low precipitation are differentiated, highlighting that from January to May, precipitation values are high, while from June to November, precipitation levels are low.

The highest mean monthly precipitation values correspond to February and March, with 539.12 mm and 571.56 mm, while July, August and September present the lowest precipitation values, with 40.85 mm, 34.84 mm and 41.73 mm, respectively.

The average annual precipitation at meteorological station INAMHI-M0124 has a 242.14 mm/year value. However, this information is not decisive for irrigation purposes since the objective of irrigation is to supply the months in which precipitation does not cover the crops' water needs.

Determination of Potential Evapotranspiration or Reference Evapotranspiration

Potential or reference evapotranspiration (ETP)

Potential or reference evapotranspiration (ETP) was obtained using the Hargreaves method, in which all the parameters described above and determined in this document are used.

Table 4. Potential or reference evapotranspiration in the study area (ETP).

Month	MF	TMF (º F)	CH	CE	ETP (mm/month)	ETP (mm/day)
January	2.788	75.73 ºF	0.513	1.0029	108.68	3.51
February	2.177	75.73 ºF	0.531	1.0029	85.45	3.05
March	2.354	77.32 ºF	0.552	1.0029	100.71	3.25
April	2.197	77.37 ºF	0.539	1.0029	91.85	3.06
May	2.137	76.41 ºF	0.512	1.0029	83.84	2.7
June	1.900	74.56 ºF	0.488	1.0029	72.54	2.42
July	2.091	73.67 ºF	0.496	1.0029	76.6	2.47
August	2.216	73.64 ºF	0.521	1.0029	85.33	2.75
September	2.256	73.91 ºF	0.544	1.0029	91.01	3.03
October	2.358	73.96 ºF	0.554	1.0029	96.88	3.13
November	2.234	74.32 ºF	0.622	1.0029	103.61	3.45
December	2.265	75.25 ºF	0.556	1.0029	95.02	3.07
Media	**2.248**	**75.16 ºF**	**0.536**	**1.003**	**90.961**	**2.991**

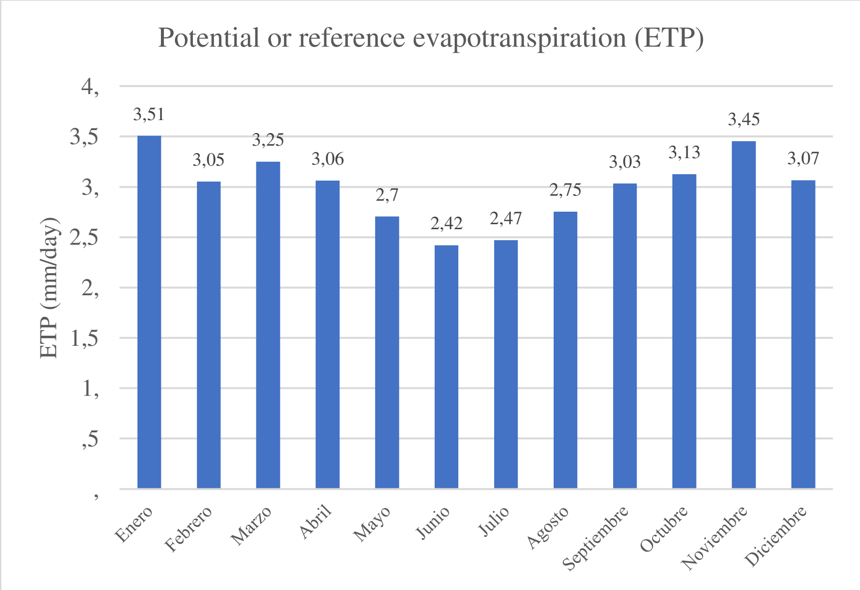

Figure 4. *Potential or reference evapotranspiration (ETP).*

Table 4 and Figure 4 show the results of potential evapotranspiration or reference evapotranspiration ETP expressed in mm/day, where it can be seen that in June and July, there are low values of 2.42 and 2.47 mm/day, while in November with a value of 3.45 mm/day and in January is 3.51 mm/day, which correspond to the months with the highest values. Considering the values obtained for each month, the average ETP during the year is 2.99 mm/day.

Determination of Crop Evapotranspiration (ETc)

Crop coefficient (kc)

The crop coefficient for cocoa (*Theobroma cacao L.) has* the following values:

Table 5. *Crop coefficient (kc)*

Cultivation	kc start period	kc mid-period	kc end of period
Cocoa	1	1.05	1.05

Source: *(FAO56, 2006)*

Table 5 shows the kc values for the cocoa crop in its different stages of development. For irrigation studies, the highest kc value is taken, which corresponds in this case to 1.05, which corresponds to the mid-period stage in which the flowering and fruiting processes of the crop take place permanently.

Effective precipitation (Pe)

The following results were obtained from the monthly average precipitation data of the meteorological station for effective precipitation in the irrigation project area expressed in mm.

Table 6. *Effective precipitation (Pe) in the project area.*

Month	Average monthly precipitation (mm)	Effective precipitation (mm)
January	448.74	169.87
February	539.12	178.91

March	571.56	182.16
April	508.65	175.87
May	272.03	152.20
June	97.72	82.44
July	40.85	38.18
August	34.84	32.89
September	41.73	38.95
October	58.07	52.67
November	63.18	56.80
December	229.21	147.92
Media	**242.14**	**109.07**

Figure 5. *Effective precipitation (Pe).*

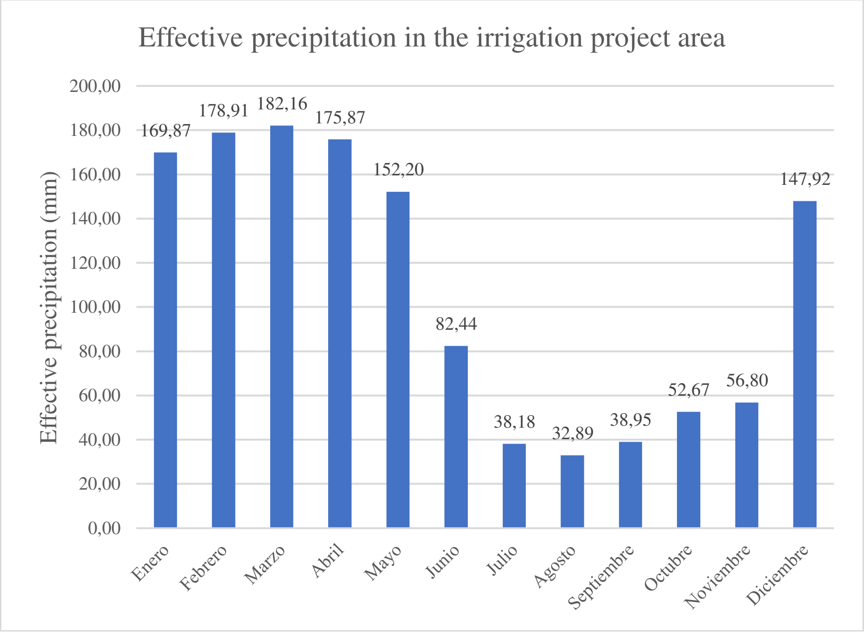

Table 6 and Figure 5 show the average monthly values of effective precipitation (Pe). For irrigation project purposes, attention should be paid to the months in which the Pe presents lower values, as in this case, the months from July to November, where values of 32.89 to 56.80 mm are presented, which would correspond to the period in which the crops could present water deficit that would consequently affect yields.

Crop evapotranspiration (ETc)

Crop evapotranspiration (ETc) considers the potential evapotranspiration (ETP) and the crop coefficient (kc), for its determination, whose results are shown in the following information

Table 7. *Effective precipitation (Pe) in the project area.*

Months	ETP (mm/month)	Crop Coefficient (kc)	ETc (mm/month)	ETc (mm/day)
January	108.68	1.05	114.12	3.68
February	85.45	1.05	89.72	3.2
March	100.71	1.05	105.75	3.41

April	91.85	1.05	96.45	3.21
May	83.84	1.05	88.03	2.84
June	72.54	1.05	76.17	2.54
July	76.6	1.05	80.43	2.59
August	85.33	1.05	89.6	2.89
September	91.01	1.05	95.57	3.19
October	96.88	1.05	101.72	3.28
November	103.61	1.05	108.79	3.63
December	95.02	1.05	99.77	3.22
Media	**90.96**	**1.05**	**95.51**	**3.14**

Table 7 shows the calculated values of monthly and daily crop evapotranspiration, from which the ETc shows a range of 2.54 to 3.68 mm/day and an average ETc for the project area and the cocoa crop with a value of 3.14 mm/day.

Crop water demand

The water demand is the amount required by the cocoa crop; considering the losses and contributions due to evapotranspiration and precipitation, the following results are shown.

Table 8. *Monthly and daily water demand of the crop.*

Months	ETc (mm/month)	Effective precipitation (mm)	Water demand mm/month	Water demand mm/day
January	114.12	169.87	-55.76	-1.80
February	89.72	178.91	-89.19	-3.19
March	105.75	182.16	-76.41	-2.46
April	96.45	175.87	-79.42	-2.65
May	88.03	152.20	-64.17	-2.07
June	76.17	82.44	-6.27	-0.21
July	80.43	38.18	42.25	1.36
August	89.6	32.89	56.70	1.83
September	95.57	38.95	56.62	1.89
October	101.72	52.67	49.05	1.58
November	108.79	56.80	51.99	1.73
December	99.77	147.92	-48.15	-1.55

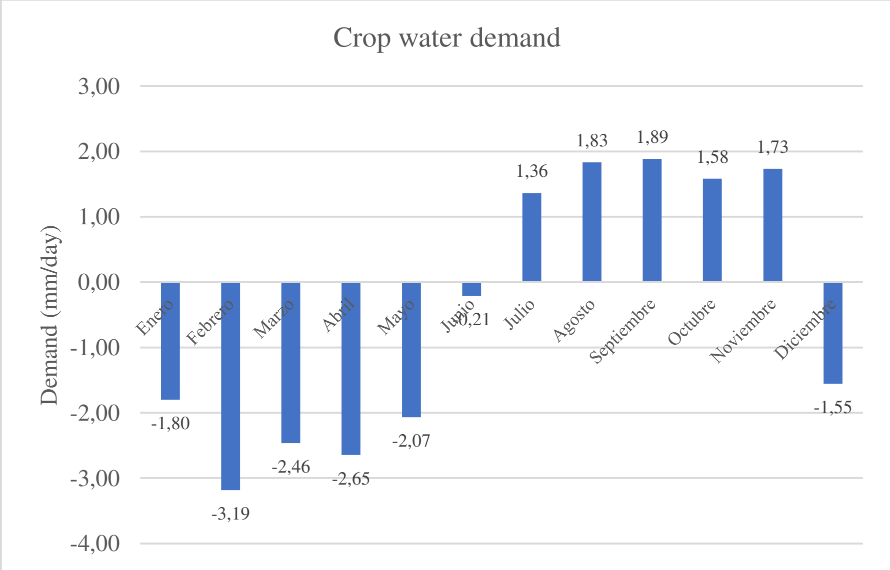

Figure 6. *Crop water demand.*

As can be seen in Table 8 and Figure 6, the calculation of crop water demand shows negative values, which means that the crop evapotranspiration (ETc) values are lower than the effective precipitation (Pe) values, so there is no need to irrigate the crop from December to May.

The crop's water demand shows positive values from July to November since ETc values are higher than Pe values, generating a water demand or water sheet that must be replenished by irrigation.

The month of September presents the highest value in terms of water demand or required water sheet with 1.89 mm/day, so this data is considered the highest water need for determining the agronomic and hydraulic design parameters.

Soil physical properties and soil water capacities

A soil sample was taken from the property and analyzed in a qualified laboratory (INIAP-Santa Catalina) to identify the physical and hydric properties, obtaining the following results:

Table 9. *Soil physical properties and soil water suitability.*

Property	Value	Unit
Field capacity (CC)	49.3	%
Permanent wilting point (PMP)	32.2	%
Bulk density (Da)	0.96	g/cc
Gravimetric humidity (Hg)	50.7	%
Volumetric humidity	48.6	%
Organic matter	2.8	%
Sand	23	%
Limo	36	%
Clay	41	%
Textural class	Clayey	

Source: *(INIAP, 2020)*

The following results were obtained in the determination of sprinkler irrigation parameters in the present research work:

Table 10. *Agronomic parameters for irrigation*

Parameter	Result
Net sheet	32.83 mm
Crude foil	43.78 mm
Maximum irrigation frequency	10 days
Actual irrigation frequency	5 days
Adjusted net sheet	9.44 mm
Adjusted gross sheet	12.58 mm
Watering time	2 hours
Volume required	161.05 m3

Prepared by: *Tapia C. (2021).*

The net lamina (dn) corresponds to a value of 32.83 mm, which is the amount of water that must be applied in irrigation to raise the moisture content of the root zone from a lower value corresponding to the depletion fraction to an upper value that coincides with the field capacity (Cadena, 2012).

The gross lamina (db) obtained corresponds to 43.78 mm, a value higher than the net lamina (dn) since it is necessary to apply a greater amount of water when considering the efficiency according to the method of irrigation water application.

The maximum irrigation frequency (Fmr), through the application of the equation, is 10 days that the crop could tolerate a water shortage, but in order to avoid water stress and to have a certain margin of moisture control of the root zone, it was defined to irrigate weekly, with a real irrigation frequency every 5 days.

If the actual irrigation frequency (Fr) is 5 days and the net daily requirement (Nn) is 1.89 mm/day, an adjusted net rainfall (dnj) of 9.44 mm is obtained.

With a net adjusted film (dnj) of 9.44 mm and the application efficiency (Ea), previously defined as 75%. An adjusted gross film (dbj) of 12.58 mm is obtained.

(Cadena, 2012) indicates that in clay soils, the infiltration rate is between 3 and 7 mm/h, so an average of 5 mm/h was used.

Considering the adjusted gross lamina (dbj) of 12.58 mm and the infiltration rate (Vi) of 5 mm/h, an irrigation time (Tr) of 2.52 hours was determined so that a time of 2 hours of irrigation can be adopted or defined to satisfy the gross or total lamina.

A characteristic flow rate of 0.29 l/s x ha is obtained, and as the total area of the irrigation project is 1.28 ha, the characteristic flow rate (qc) results in 0.37 l/s. This means that this flow must be permanently available for irrigation application.

A total volume (Vt) of 161.05 m^3 is obtained, which is required for the application of irrigation by the sprinkler method to satisfy the demand of the area and lamina indicated above.

Selection of sprinkler type

The type of sprinkler selected for irrigation water application comprises the following characteristics:

Table 11. *Technical specifications of the sprinkler for irrigation in the project.*

SPRINKLER CHARACTERISTICS	
TYPE	IMPACT
MODEL	NAANDAN JAIN 50-22
NUMBER OF NOZZLES	2
NOZZLE SIZE	3.0 X 1.8 mm
OPERATING PRESSURE	2.5 - 4 bar
OPERATING FLOW RATE	0.21 l/s
OPERATING PRESSURE	2.5 bar
WETTED DIAMETER	21.5 m

Prepared by: *Tapia C. (2021).*
Source: *(NAANDANJAIN IRRIGATION, 2011)*

Calculated spacing between sprinklers (Ea) and laterals (El)

A spacing between sprinklers (Ea) equal to 10.75 m was obtained. In order to define a spacing that is manageable for construction purposes, a value of 10 m was determined.

In order to have a quadratic sprinkler arrangement, the spacing between laterals (El) was also set at 10 m, resulting in a 10 x 10 m irrigation frame.

Rainfall or Sprinkler application intensity (Ia)

The operating flow rate of the selected sprinkler is 760 l/h and the irrigation frame determined by the spacing between sprinklers and laterals corresponds to 100 m^2, with which a rainfall or application intensity (Ia) of the sprinkler corresponding to 7.60 mm/h was determined.

Sprinkler run time

The irrigation time per sprinkler position is 2.21 hours, so 2 hours of sprinkler operation time may be required to meet the system demand.

System rainfall (Ps)

The rainfall of the irrigation system (Ps) obtained is 6.30 mm/h, while the sprinkler application intensity (Ia) is 7.60 mm/h, so it can be defined that the choice of sprinkler is adequate since the condition that the sprinkler application intensity must be greater than or equal to the system rainfall is fulfilled.

Number of irrigation sectors (Ns)

The effective irrigation day determined for this project is 8 hours, and the irrigation time per sprinkler position is 2 hours, so the number of sectors that can be determined is 4, i.e., the total area of the project (1.28 ha) can be irrigated in 4 sections during the 8 hours of irrigation.

Conclusions

In the agronomic design, it was determined that the water demand of the cocoa crop (*Theobroma cacao*) in the San Francisco de Chipe area is decisive from July to November, in

September where the water requirement is highest with a rainfall of 1.89 mm/day, which justifies the incorporation of the irrigation system in this locality.

Considering an irrigation frequency of 5 days, crop demand of 1.89 mm/day and application efficiency of 75%, it was determined that a total required rainfall of 12.58 mm should be satisfied in each sprinkler irrigation application, with a time of 2 hours, for which a volume of 161.05 m^3 is required for a surface of 1.28 ha.

The selected sprinkler is of the impact type with an operating flow rate of 0.21 l/s, a working pressure of 2.5 bar and a reach diameter of 21.5 m (60 ft). The irrigation frame is 10 m x 10 m, achieving an application intensity of 7.60 mm/h, requiring a sprinkler positioning time of 2 hours to satisfy the total lamina.

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