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BALANÇO HÍDRICO PARA O CULTIVO DO CAFÉ (*Coffea canephora*) NOS MUNICÍPIOS DE RIO BRANCO, TARAUACÁ E CRUZEIRO DO SUL, ACRE

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1 RESUMO

O balanço hídrico é uma relevante ferramenta para a determinação dos períodos de deficiência e excedente hídrico que interferem no crescimento, no desenvolvimento e na produção dos cafeeiros. O objetivo desta pesquisa foi determinar o balanço hídrico para a cultura do café (*Coffea canephora)* nos municípios de Rio Branco, Tarauacá e Cruzeiro do Sul, Acre, baseando-se nas séries de dados disponíveis no Instituto Nacional de Meteorologia (INMET), considerando-se um solo de textura média, com capacidade de água disponível (CAD) de 55 mm, diferentes coeficientes de cultura (Kc) e espaçamento entre linhas longo, adensado e super-adensado. A deficiência hídrica anual nos municípios de Rio Branco e Tarauacá, Acre, variou de 96 a 384 mm e de 55 a 358 mm, respectivamente, podendo comprometer as fases fenológicas vegetativa e reprodutiva do cafeeiro (*Coffea canephora*), evidenciando a necessidade crucial do uso da irrigação suplementar nessas localidades. Enquanto, em Cruzeiro do Sul, Acre, ocorreu a menor deficiência hídrica anual entre as localidades avaliadas, que oscilou de 23 a 237 mm no período de maio a setembro, sendo também indicada a irrigação suplementar regular nessa localidade.

Palavras-Chave: coeficiente de cultivo, deficiência hídrica, evapotranspiração**.**

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WATER BALANCE FOR CULTIVATION OF COFFEE (*Coffea canephora*) IN THE MUNICIPALITIES OF RIO BRANCO, TARAUACÁ AND CRUZEIRO DO SUL, ACRE

2 ABSTRACT

The water balance is an important tool for determining periods of water deficiency and surplus that interfere with the growth, development, and production of coffee trees. This research aimed to determine the water balance for the coffee crop (*Coffea canephora*) in the municipalities of Rio Branco, Tarauacá, and Cruzeiro do Sul, Acre, based on the data series available at the National Institute of Meteorology (INMET), considering a medium-textured soil with available water capacity (AWC) of 55 mm, different crop coefficients (Kc), and long, dense, and super-

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dense crop row spacing. The annual water deficiency in the municipalities of Rio Branco and Tarauacá, Acre, ranged from 96 to 384 mm and from 55 to 358 mm, respectively, which may compromise the vegetative and reproductive phenological phases of coffee plants (*Coffea canephora*), highlighting the crucial need for the use of supplementary irrigation in these locations. While, in Cruzeiro do Sul, Acre, there was the lowest annual water deficiency among the locations evaluated, which oscillated from 23 to 237 mm from May to September, so that regular supplementary irrigation is also indicated in this location.

Keywords: cultivation coefficient, water deficiency, evapotranspiration.

3 INTRODUCTION

Coffee farming plays a relevant role in Brazil's social and economic development, ensuring the generation of jobs throughout the production chain, the retention of people in the countryside, and tax collection (AVELLAR; BOTELHO; ORTEGA, 2017). According to the National Supply Company (CONAB, 2017), the 44.7 million bags of coffee produced in the country in 2017 represent a total cultivated area of 2,208.9 thousand hectares (345.2 thousand hectares in formation and 1,863.7 thousand hectares in production), with an average productivity of 1,380 kg/hectare for Arabica coffee (*Coffea arabica L.) and 1,683 kg per hectare for Coffea* coffee *canephora*.

In the state of Acre, *Coffea canephora* accounts for approximately 98% of coffee production, with 909 tons harvested in an area of 661 hectares and an average productivity of 1,375 kg/ha, which is lower than the national average. The coffee plantations in Acre are located mainly in the municipalities of Acrelândia, Braziléia, and Manuel Urbano, with approximately 50, 17, and 7% of the total cultivated area, respectively (IBGE, 2017). Despite its social and economic importance, coffee farming is not very competitive in the region due to structural and logistical deficiencies and the low level of technology adoption (ALVARES *et al*., 2018).

According to Amaral *et al*. (2018), climatic conditions influence the growth, development, and productivity of agricultural crops. According to Gonçalves (2001), the meteorological variables that most directly influence changes in the phenological phases of permanent crops are rainfall and air temperature, with soil water availability being one of the main determinants of annual productivity. According to Araújo *et al*. (2018), in the vegetative phase of the coffee plant, soil water is necessary to promote the growth of plagiotropic branches and, in the reproductive phase, to develop fruits and achieve satisfactory productivity.

The study of water relationships in coffee plants is of particular interest since small reductions in water availability can substantially reduce their growth, even if no wilting of leaves or any other visible signs of water deficit are observed (DAMATTA; RAMALHO, 2006). Knowledge of how plants use water in the soil and their response to different levels of water availability on the basis of the water balance can be a viable solution for establishing effective management strategies aimed at the best possible use of soil water reserves by crops (SILVA *et al*., 2011).

The crop water balance is a fundamental tool for estimating soil water deficiency and surplus, which interferes with the growth, development and productivity of coffee plants. Its sequential calculation makes it possible to indicate periods of water deficiency, that is, periods in which there is a need for supplementary irrigation, in addition to quantifying the irrigation needs of a crop (CAMARGO; PEREIRA, 1990).

For Santinato, Fernandes and Fernandes (1996), the water suitability of coffee can be considered suitable in regions where the annual water deficit varies between 150 mm and 200 mm, whereas regions with an annual water deficit between 200 mm and 400 mm can be considered suitable only when supplemental irrigation is used. The use of irrigation techniques in agriculture can contribute to improving the performance of agribusiness in a region and can be considered an important element in agricultural diversification, in addition to enabling off-season harvests and better-quality products (MARTINS *et al*., 2011).

The objective of this work was to determine the water balance for coffee cultivation (*Coffea canephora*). in the municipalities of Rio Branco, Tarauacá and Cruzeiro do Sul, Acre, considering an available water capacity (AWC) of 55 mm in medium-textured soil.

4 METHODOLOGY

The state of Acre has a population of 881,935 inhabitants, distributed in 22 municipalities in two mesoregions, the Acre Valley to the east and the Juruá Valley to the west, both with five development regions: Alto Acre, Baixo Acre, Purus, Tarauacá/Envira and Juruá (GOVERNMENT OF THE STATE OF ACRE, 2010; IBGE, 2019). The municipality of Rio Branco, AC, is located in the Baixo Acre region, whereas the localities of Tarauacá and Cruzeiro do Sul, AC, are located in the Juruá region.

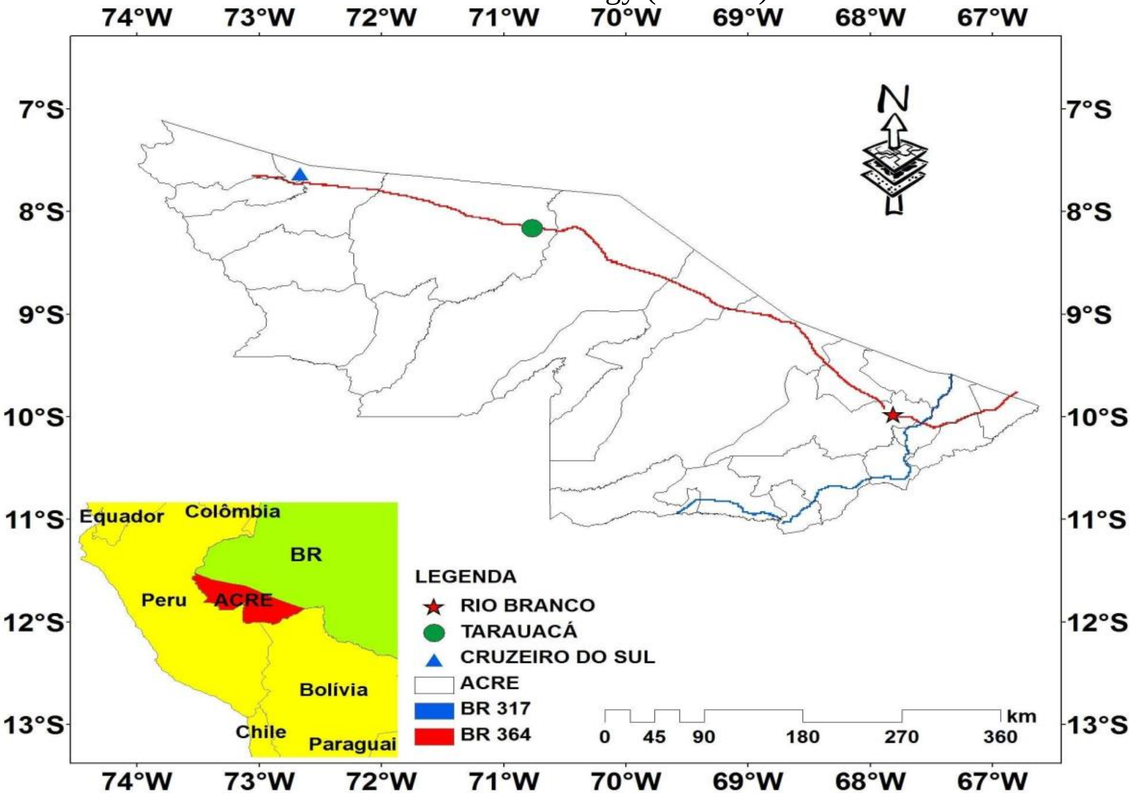
In the Amazon basin, the density of meteorological stations with series exceeding 30 years of continuous and consistent data is very low (MARCOLAN; SPINDULA, 2015). In such situations, the World Meteorological Organization (WORLD METEOROLOGICAL ORGANIZATION, 2003) recommends the calculation of provisional climatological normals, which are short-term averages based on observations spanning a minimum period of 10 years. Information regarding the classification of the meteorological data series as well as the geographic locations of the municipalities in the state of Acre covered in this study are presented in Table 1 and Figure 1.

Table 1. Classification of the meteorological data series, geographic locations of the municipalities evaluated and intervals considered.

Municipalities	**Data series type**	**Geographical location**			**Data series range (years)**
		Latitude (S)	**Longitude (W)**	**Altitude (m)**	
Rio Branco	Climatological normal	09° 58' 22”	67° 48' 40”	160.71	1990-2019
Tarauacá	Provisional climatological normal	08° 08′ 08″	70° 45′ 54″	179.0	1994-2019
Southern Cross	Provisional climatological normal	07° 37' 52"	72° 40' 12"	182.0	1993-2014

Source: INMET (2019).
* Data series type: WORLD METEOROLOGICAL ORGANIZATION, 1983.

Figure 1. Geographic location from the area of study and to the conventional meteorological stations of the National Institute of Meteorology (INMET).



Source: Delgado *et al*. (2012).

The data used in this work were obtained from the Meteorological Database for Teaching and Research - BDMET of INMET, available on the internet (INMET, 2019). Priority was given to meteorological stations in locations with data series of more than ten years. Conventional meteorological stations in Rio Branco, Tarauacá and Cruzeiro do Sul, Acre, carry out daily observations at world standard times of 12, 18 and 24 UTC (Coordinated Universal Time).

The reference evapotranspiration used to calculate the water balance of the coffee crop in the municipality of Rio Branco, Acre, was estimated via the Penman–Monteith method (Equation 1), parameterized by the Food and Agriculture Organization of the United Nations-FAO (ALLEN *et al*., 1998).

$$ETo = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0{,}34u_2)} \qquad (1)$$

Where ETo is the reference evapotranspiration (mm d $^{-1}$); Δ is the slope of the vapor pressure curve (kPa °C $^{-1}$); Rn is the total daily net radiation (MJ m $^{-2}$ d $^{-1}$); G is the soil heat flux (MJ m $^{-2}$ d $^{-1}$); γ is the psychrometric constant (kPa °C $^{-1}$); T_a is the average daily air temperature (°C); u_2 is the average wind speed measured at 2 m height (ms $^{-1}$); $_s$ is the saturation pressure of water vapor (kPa); and the partial pressure of water vapor (kPa) is used.

In calculating the water balance of coffee crops for the municipalities of Tarauacá and Cruzeiro do Sul, Acre, the reference evapotranspiration was estimated via the methods of Camargo (1971) and Thornthwaite (1948), according to Equations 2 and 3, respectively.

$$\text{EToC} = 0{,}01 * \text{Qo} * \text{Tmed} * \text{ND} \quad (2)$$

where EToC is the reference evapotranspiration via the Camargo method (1971); Qo is the extraterrestrial global solar irradiance, expressed in millimeters of equivalent evaporation per day (mm d $^{-1}$); Tmed is the average daily air temperature (°C); and ND is the number of days in the period considered.

$$\text{EToTh} = 16\left(\frac{10Tn}{I}\right)^{a} \quad \text{to} \quad Tn > 0\ °\text{C} \quad (3)$$

where EToTh is the monthly reference evapotranspiration estimated via the Thornthwaite method (1948); Tn is the average monthly air temperature for any given year (°C); and I and a correspond to the heat indices of the region, which are calculated via Equations (4) and (5), respectively.

$$\text{I} = \sum_{n=1}^{12}((0{,}2\text{Tn})^{1{,}514}) \quad \text{para} \quad Tn > 0\ °\text{C} \quad (4)$$

$$\text{a} = 6{,}75\text{x}10^{-7}\, I^{3} - 7{,}71\text{x}10^{-5} I^{2} + 1{,}7912\text{x}10^{-2} I + 0{,}49239 \quad (5)$$

The monthly evapotranspiration estimated via the Thornthwaite method, corrected (EToTh $_{C}$), was obtained from the standard potential evapotranspiration, applying a correction factor according to Equation (6).

$$EToTh_{C} = EToThx\frac{N}{12}x\frac{ND}{30} \quad (6)$$

where N is the average monthly photoperiod and ND is the average number of days in the period.

On the basis of the EToC and EToThc values obtained, ETo was estimated in the municipalities of Tarauacá and Cruzeiro do Sul via the Penman–Monteith method via the multiple linear regression model (Equation 7) proposed by Allen *et al*. (1998).

$$\text{y} = 0{,}17531 + 1{,}28185\ (\text{V1}) - 0{,}36008\ (\text{V2}) \quad (7)$$

where y is the log value (ETo value obtained via the Penman–Monteith method), V1 is the log value (ETo value obtained via the Camargo method), and V2 is the log value (ETo value obtained via the Thornthwaite method). Considering that the regression equation uses transformed data, it is necessary to invert the parameter (ETo (mm/month)= 10^{y}).

To calculate the water balance for coffee crops (*Coffea canephora*), the methodologies proposed by Thornthwaite (1948) and Thornthwaite and Mather (1955) were used with the aid of the BHnorm program, which was prepared in an EXCEL ® spreadsheet by Rolim, Sentelhas and Barbieri (1998), for a CAD of 55 mm, referring to medium-textured soil. The results of research on edaphoclimatic zoning for the cultivation of *Coffea canephora* in Acre indicate that medium-textured soils are suitable for planting coffee in the altered areas of the Alto and Baixo Acre regions: Purus/Tarauacá-Envira and Juruá (ARAÚJO *et al.*, 2018).

The values of the cultivation coefficient (kc) used in the calculation of the water balance of the coffee crop for the evaluated locations were obtained by Santinato and Fernandes (2005) in the state of Minas Gerais in irrigated coffee plants with different planting ages planted in medium-textured soil (Table 2).

Table 2. Cultivation coefficient (Kc) for coffee in medium-textured soil, age and spacing between rows and between plants.

A - For long spacing: 3.5 to 4.0 m between rows x 0.5 to 0.7 m between plants	
Coffee tree age (years)	
< 1.5	0.9
1.5-3.0	1.0
> 3.0	1.1
B - For dense spacing: 1.5 to 2.5 m between rows x 0.5 to 0.7 m between plants	
< 1.5	1,2
1.5-3.0	1.3
> 3.0	1.3
C - For super dense spacing: < 1.5 m between rows x 0.5 to 0.7 m between plants	
< 1.5	1.4
1.5-3.0	1.5
> 3.0	1.5

Source: Santinato and Fernandes (2005).

The physical-hydric characteristics, i.e., field capacity at a stress of 0.01 MPa, permanent wilting point at a stress of 1.5 MPa and apparent density for a medium-textured soil, are presented in Table 3 (VERMEIREN; JOBLING, 1997). To determine the real water capacity (WRC), the methodology proposed by Bernardo, Soares and Mantovani (2006) for a medium-textured soil was used.

Table 3. Moisture at the field capacity (CC) and permanent wilting point (PMP), available water (AD), apparent density (Da), effective depth of the coffee root system (Z), water availability factor (f) and real water capacity (CRA) for a medium-textured soil.

Soil texture	CC (%)	PMP (%)	AD (%)	From the (g cm $^{-3}$)	Z (cm)	f (%)	CRA (mm)
Average	27	13	14	1.35	30	40	21.00

Source: Vermeiren and Jobling (1997); Bernardo, Soares and Mantovani (2006)

5 RESULTS AND DISCUSSION

Tables 4, 5 and 6 present the monthly average values of air temperature and rainfall for the localities of Rio Branco, Tarauacá and Cruzeiro do Sul, Acre. The temperatures were favorable for coffee cultivation in the three municipalities evaluated. Taques and Dadalto (2007) established technical parameters for the climatic zoning of this crop, indicating that the annual thermal limits for regions classified as suitable, marginal and unsuitable are 22 to 26 °C, 21 to 22 °C, 26 to 27 °C, and < 21 °C or > 27 °C, respectively.

Table 4. Air temperature: minimum, average and maximum, precipitation and standard deviation (SD) for Rio Branco, Acre, 1990--2019.

	Air temperature (°C)						**Precipitation (mm)**	
Month	Minimum	DP	Average	DP	Maximum	DP	Average	DP
Jan	22.5	1	25.8	0.5	30.9	0.7	286	97
Feb	22.4	1	25.7	0.5	30.8	0.5	298	82
Sea	22.5	1	25.8	0.4	31	0.5	292	98
Apr	21.9	1.1	25.7	0.5	31.3	0.7	204	87
May	20.6	1.5	24.8	1	30.6	0.9	96	44
June	19.1	1.4	24.1	1.1	30.6	1.1	45	40
Jul	18.1	1	23.8	0.9	31.7	1.4	29	24
Aug	18.8	1,2	25	1	33.3	1.1	58	40
Set	20.7	1.1	26	0.7	33.6	1	95	58
Out	22.1	0.7	26.4	0.5	33.1	0.6	147	57
Nov	22.5	0.7	26.2	0.5	32	0.6	214	74
Ten	22.6	0.7	26.1	0.4	31.2	0.6	260	80

Source: INMET (2019); SOUSA (2020 c).

Table 5. Air temperature: minimum, average and maximum, precipitation and standard deviation (SD) for Tarauacá, Acre, 1994--2019.

	Air temperature (°C)						**Precipitation (mm)**	
Month	Minimum	DP	Average	DP	Maximum	DP	Average	DP
Jan	22.7	0.4	25.8	0.6	31	0.8	319	109
Feb	22.8	0.5	26	0.5	31	0.6	272	78
Sea	22.8	0.7	26	0.6	31.2	0.5	340	84
Apr	22.6	0.6	26	0.4	31.6	0.6	202	67
May	21.5	1.4	25.5	0.6	31	0.7	137	69
June	20.5	1	25	0.9	30.9	0.7	74	44
Jul	19.5	0.9	24.9	0.8	31.9	1	46	36
Aug	20.1	0.8	25.8	0.9	33.4	0.9	66	44
Set	21.5	0.6	26.4	1	33.6	0.9	119	58
Out	22.7	0.4	26.6	0.8	32.9	0.5	183	70
Nov	22.9	0.7	26.3	0.8	32.1	0.4	241	93
Ten	22.9	0.3	26	0.5	31.3	0.5	288	80

Source: INMET (2019); SOUSA (2020 a).

Table 6. Air temperature: minimum, average and maximum, precipitation and standard deviation (SD) for Cruzeiro do Sul, Acre, 1993--2014.

	Air temperature (°C)						**Precipitation (mm)**	
Month	Minimum	DP	Average	DP	Maximum	DP	Average	DP
Jan	21.8	1,2	25.9	0.5	31.3	0.8	236	77
Feb	21.8	1,2	25.7	0.6	31.2	0.8	247	90
Sea	21.8	1.3	25.7	0.6	31.3	0.9	274	93
Apr	21.6	1.4	25.7	0.7	31.4	0.9	209	84
May	20.9	1.3	25.3	0.6	31	0.9	148	62
June	19.9	1.6	24.9	0.8	30.9	0.9	88	49
Jul	19	1.8	24.8	0.9	31.4	1.1	71	48
Aug	19.5	1.8	25.4	0.8	32.4	1.1	75	36
Set	20.4	1.7	25.9	0.8	32.7	1	119	61
Out	21.2	1.8	26	0.7	32.4	0.5	178	72
Nov	21.5	1.9	25.9	0.6	31.9	0.8	206	93
Ten	21.5	1.9	25.8	0.6	31.5	0.8	231	67

Source: INMET (2014); SOUSA (2020 b).

In the evaluated locations, annual rainfall is well distributed and favorable for coffee planting (Tables 4, 5 and 6). According to Marcolan *et al*. (2009), the ideal rainfall for Arabica coffee is between 1,200 and 1,800 mm. However, this value can also be applied to the coffee plant *Coffea canephora*, although this variety presents better adaptation than *Coffea arabica* in locations where rainfall exceeds 2,000 mm.

In Rio Branco, Acre, monthly rainfall greater than 100 mm occurred from October to April, accounting for approximately 84% of the annual rainfall during this period, whereas in Tarauacá and Cruzeiro do Sul, Acre, rainfall greater than 100 mm was recorded from September to May, accounting for approximately 92 and 89% of the annual rainfall, respectively (Tables 4, 5 and 6). According to Martins *et al*. (2007), for the conditions in Brazil, during the vegetation and fruiting phases, which occur from October to May, the coffee plant requires readily available soil moisture.

5.1 Water balance for coffee cultivation (*Coffea canephora*) in the municipality of Rio Branco, Acre

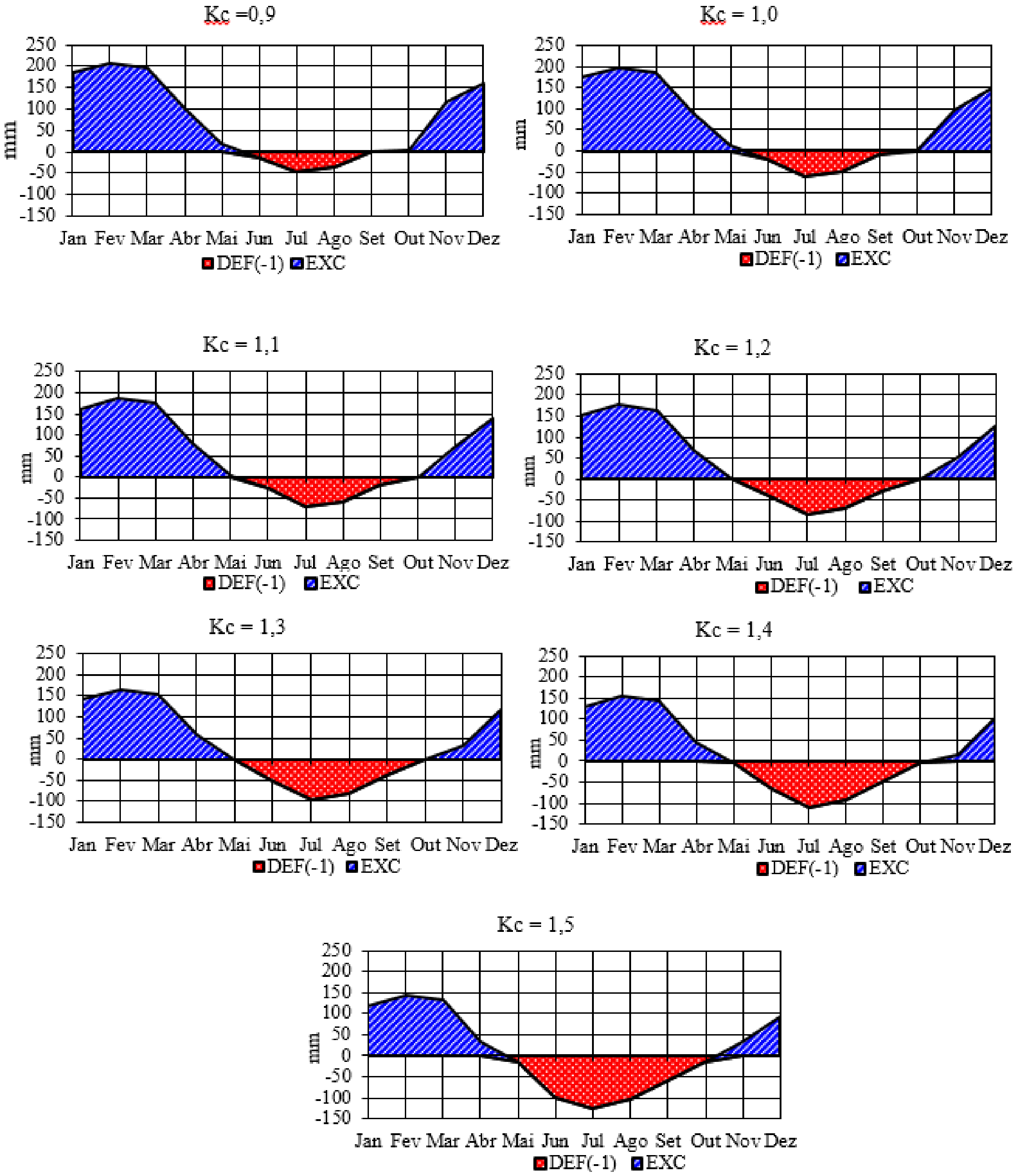
Table 7 presents the water balance of coffee cultivation (*Coffea canephora*) in Rio Branco, AC, for a water availability of 40% in a medium-textured soil with a CAD of 55 mm. In coffee plants with a crop coefficient of 0.9, an annual water deficiency of 96 mm occurred, which was distributed from June to August. However, for the same crop, when crop coefficients equal to 1.0, 1.1 and 1.2 were adopted, annual water deficiencies of 132, 173 and 219 mm, respectively, were observed in the period from June to September. When a crop coefficient equal to 1.3 was adopted, an annual water deficiency of 268 mm was observed, which was distributed from May to September. However, when the crop coefficients were equal to 1.4 and 1.5, annual water deficiencies of 323 and 384 mm, respectively, were recorded from May to October (Figure 2). Inferior results were obtained by Scerne *et al*. (2000)

Table 7. Water balance extract for coffee cultivation (*Coffea canephora*) in the municipality of Rio Branco, AC, considering 40% available water, medium texture soil and CAD=55 mm.

Month	Crop coefficient (kc)													
	0.9		1.0		1.1		1,2		1.3		1.4		1.5	
	Def *	Exc *	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc
Jan	0	286	0	174	0	163	0	152	0	140	0	129	0	118
Feb	0	206	0	196	0	186	0	176	0	166	0	155	0	145
Sea	0	196	0	186	0	175	0	164	0	154	0	143	0	132
Apr	0	102	0	91	0	79	0	68	0	57	0	45	0	34
May	0	20	0	12	0	3	0	0	2	0	4	0	7	0
June	14	0	20	0	26	0	37	0	50	0	64	0	77	0
Jul	46	0	58	0	70	0	83	0	96	0	108	0	120	0
Aug	36	0	47	0	59	0	70	0	82	0	93	0	104	0
Set	0	0	7	0	18	0	28	0	38	0	49	0	59	0
Out	0	0	0	0	0	0	0	0	0	0	5	0	16	0
Nov	0	117	0	92	0	69	0	47	0	25	0	9	0	0
Ten	0	160	0	149	0	137	0	126	0	115	0	104	0	91
Year	96	1,087	132	899	173	813	219	733	268	657	323	129	384	521

* Def = water deficiency; ** Exc = water surplus.

Figure 2. Graphical representation of the water balance extract of coffee cultivation (*Coffea canephora*) in the municipality of Rio Branco, Acre, in medium-textured soil with an available water capacity = 55 mm and cultivation coefficients (Kc) ranging from 0.9--1.5.



In the municipality of Rio Branco, Acre, coffee presented annual water deficits ranging from 96 to 384 mm, thus highlighting the possibility of using supplementary irrigation in the region. Lower results were obtained by Santinato and Fernandes (2005). The annual water surpluses ranged from 1,087 to 521 mm, considering cultivation coefficients of 0.9 and 1.5, respectively.

5.2 Water balance for coffee cultivation (*Coffea canephora*) in the municipality of Tarauacá, Acre

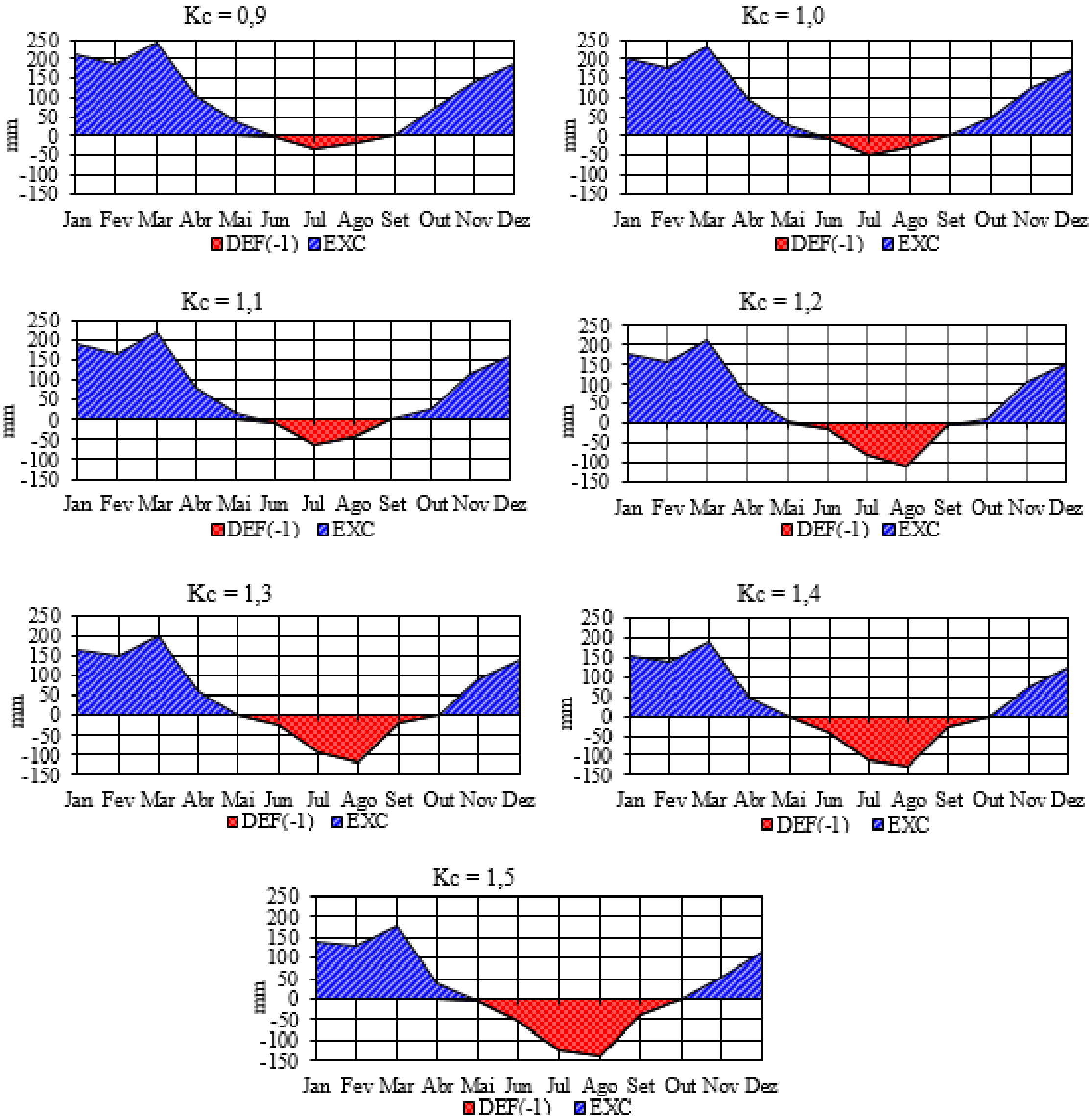
Table 8 and Figure 3 present the water balance of coffee cultivation (*Coffea canephora*) for the locality of Tarauacá, AC, considering 40% water availability in a medium-textured soil with a CAD of 55 mm.

Table 8. The water balance of coffee cultivation (*Coffea canephora*) was extracted for the municipality of Tarauacá, AC, considering 40% available water, medium textured soil, available water capacity = 55 mm and cultivation coefficients ranging from 0.9--1.5.

Month	Crop coefficient (kc)													
	0.9		1.0		1.1		1,2		1.3		1.4		1.5	
	Def *	Exc *	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc
Jan	0	212	0	200	0	188	0	177	0	165	0	153	0	141
Feb	0	186	0	176	0	167	0	157	0	147	0	138	0	128
Sea	0	243	0	232	0	221	0	210	0	199	0	189	0	178
Apr	0	104	0	93	0	82	0	71	0	61	0	50	0	39
May	0	39	0	28	0	17	0	6	0	0	2	0	6	0
June	2	0	6	0	10	0	15	0	25	0	38	0	52	0
Jul	33	0	47	0	62	0	76	0	92	0	108	0	123	0
Aug	19	0	30	0	41	0	108	0	118	0	128	0	138	0
Set	0	0	0	0	0	0	7	0	17	0	28	0	39	0
Out	0	70	0	46	0	23	0	8	0	0	0	0	0	0
Nov	0	138	0	127	0	115	0	104	0	90	0	68	0	46
Ten	0	184	0	172	0	161	0	149	0	137	0	126	0	114
Year	55	1,175	83	1,074	113	974	207	882	252	799	305	722	358	646

* Def = water deficiency; ** Exc = water surplus.

Figure 3. Graphical representation of the water balance extract used for coffee cultivation (*C. canephora*) in the municipality of Tarauacá, Acre, in medium-textured soil (CAD=55 mm), with cultivation coefficients (Kc) ranging from 0.9--1.5.



For coffee cultivation in medium-textured soil, crop coefficients of 0.9, 1.0, 1.1, and 1.2 and annual water deficiencies of 55, 83, 113, and 207 mm, respectively, were recorded from June to August, when rainfall is scarce in Tarauacá, Acre. For coffee plants with a crop coefficient of 1.3, an annual water deficiency of 252 mm was observed from June to September. Moreover, for crop coefficients of 1.4 and 1.5, annual water deficiencies of 305 and 358 mm, respectively, were observed, which were distributed from May to September (Table 8 and Figure 3). According to Marcolan *et al*. (2009), soil water deficiency inhibits the development of the coffee root system, especially the absorbent roots, reducing nutrient absorption, shoot growth and grain production.

In Tarauacá, Acre, for a scenario in which coffee is grown in medium-textured soil, an annual water deficit ranging from 55 to 358 mm was observed, indicating the possibility of using irrigation techniques at this location. These results are lower than those obtained here for Rio Branco, Acre, where an annual water deficiency ranging from 96 to 384 mm was observed, also highlighting the need to use supplementary irrigation at this location.

Among the locations evaluated, the municipality of Tarauacá, Acre, presented the largest annual water surpluses for cultivated coffee in a medium-textured soil, with values decreasing from 1,175 to 646 mm in agricultural scenarios in which cultivation coefficients of 0.9 and 1.5 were adopted, respectively.

5.3 Water balance for coffee cultivation (*Coffea canephora*) in the municipality of Cruzeiro do Sul, Acre

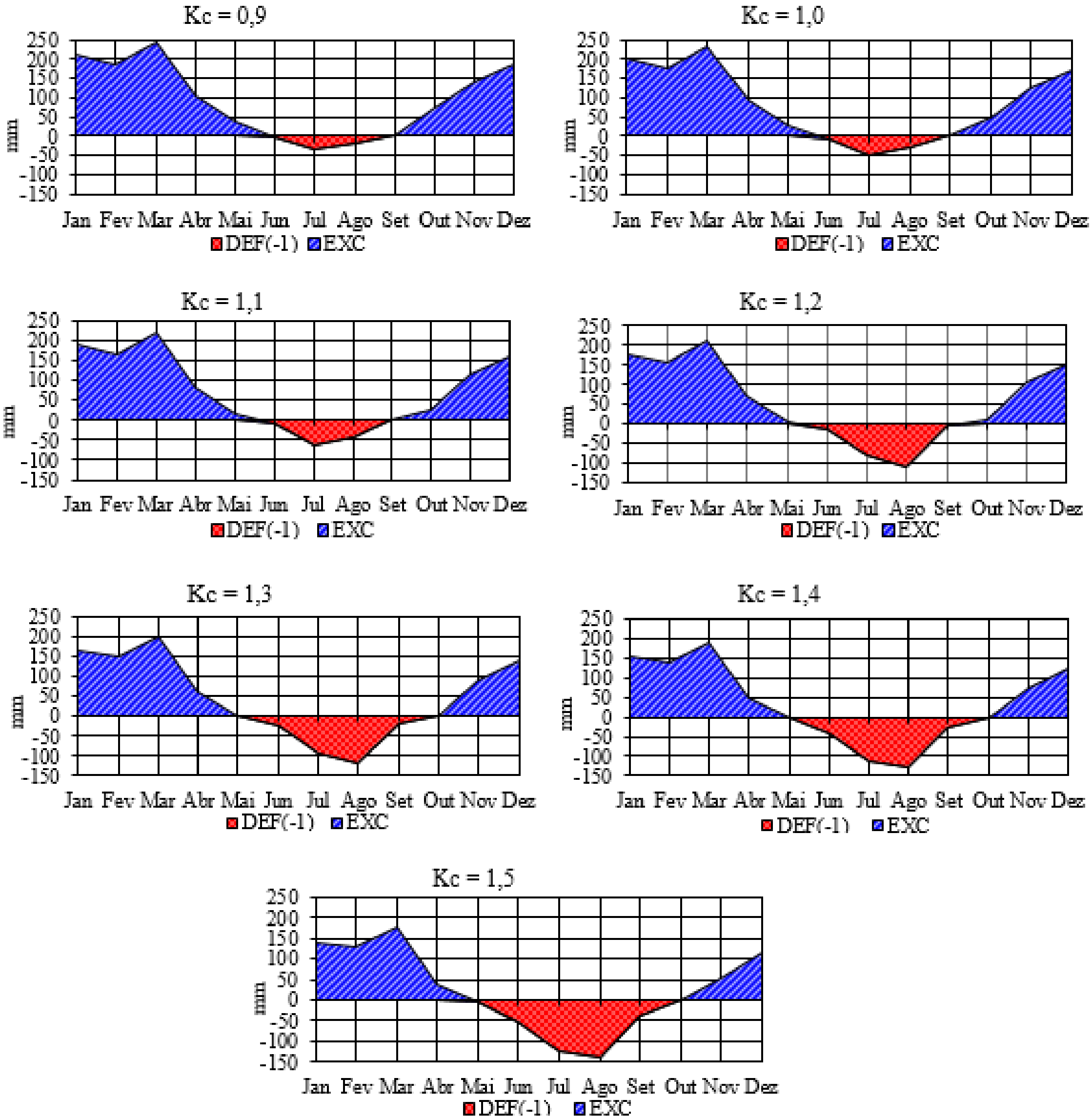
Table 9 presents the water balance of coffee cultivation (*C. canephora*) for the locality of Cruzeiro do Sul, AC, considering 40% water availability in a medium-textured soil with an available water capacity of 55 mm. For the cultivation coefficients of 0.9 and 1.0, water deficiencies of 23 and 43 mm, respectively, were recorded throughout the year and were distributed in the months of July and August (Figure 4). However, when cultivation coefficients of 1.1 and 1.2 were adopted, greater water deficiencies of 70 and 99 mm, respectively, were observed in the months of June, July and August. Moreover, for cultivation coefficients equal to 1.3 and 1.4, even greater annual water deficiencies were observed, equal to 138 and 184 mm, respectively, in the months of June to September. For the crop coefficient of 1.5, the greatest annual water deficiency, equal to 237 mm, was recorded in the period from May to September. Although coffee has a reasonable tolerance to water deficiency, irrigated crops present higher productivity than conventional, nonirrigated crops do, especially in years in which rainfall is poorly distributed (MARTINS *et al*., 2007). Santinato, Fernandes and Fernandes (1996) reported increases in productivity of 48% in irrigated coffee plants compared with nonirrigated coffee plants.

Table 9. The water balance of coffee crops (*Coffea canephora*) was extracted for the municipality of Cruzeiro do Sul, AC, considering 40% available water, medium textured soil and available water capacity = 55 mm.

Month	**Crop coefficient (kc)**													
	0.9		1.0		1.1		1,2		1.3		1.4		1.5	
	Def *	Exc *	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc	Def	Exc
Jan	0	136	0	125	0	114	0	103	0	92	0	81	0	70
Feb	0	146	0	135	0	124	0	113	0	102	0	90	0	79
Sea	0	177	0	166	0	156	0	145	0	134	0	123	0	112
Apr	0	120	0	110	0	100	0	90	0	80	0	71	0	61
May	0	50	0	39	0	28	0	17	0	6	0	0	2	0
June	0	3	0	0	2	0	5	0	9	0	17	0	28	0
Jul	9	0	18	0	31	0	44	0	58	0	74	0	91	0
Aug	14	0	24	0	37	0	49	0	62	0	74	0	86	0
Set	0	0	0	0	0	0	0	0	9	0	19	0	29	0
Out	0	76	0	46	0	20	0	0	0	0	0	0	0	0
Nov	0	110	0	99	0	88	0	73	0	49	0	26	0	4
Ten	0	133	0	122	0	111	0	100	0	89	0	78	0	67
Year	23	950	43	841	70	740	99	641	138	552	184	469	237	394

* Def = water deficiency; ** Exc = water surplus.

Figure 4. Graphical representation of the water balance extract used for coffee cultivation (*C. canephora*) in the municipality of Cruzeiro do **Sul**, Acre, in medium-textured soil (available water capacity = 55 mm), with cultivation coefficients (Kc) ranging from 0.9--1.5.



In the municipality of Cruzeiro do Sul, AC, coffee (*Coffea canephora*) in medium-textured soil presented the lowest annual water deficit among the evaluated locations, with values ranging from 23--237 mm. However, there is still a need for supplemental irrigation in the region. As advantages of coffee irrigation, Mantovani and Soares (2003) reported the anticipation of the first harvest by up to one year, the reduction in the seedling replanting rate, greater production in the first harvest, the possibility of fertigation, and the extension of the planting season, among other advantages. Martins *et al.* (2011) emphasized that irrigation is one of the fundamental techniques for increasing productivity, which must be complemented with the control of weeds, pests and diseases; pruning; disbudding; top dressing; and the use of genetic material compatible with the technology to be employed. Considering that coffee farming in the state of Acre is located mainly on small rural properties, an economic analysis is recommended since the costs of implementing irrigation systems on family properties are still high.

The municipality of Cruzeiro do Sul, Acre, presented the lowest annual water surplus among the locations evaluated for coffee (*Coffea canephora*) in medium-textured soil, with values decreasing from 950 to 394 mm and cultivation coefficients of 0.9 and 1.5, respectively.

6 CONCLUSION

The annual water deficiency in coffee (*Coffea canephora*) in the municipalities of Rio Branco and Tarauacá, Acre, on medium-textured soils ranges from 96–384 mm (May--October) and from 55–358 mm (May--September), respectively, which can compromise the vegetative and reproductive phenological phases of the coffee plant, highlighting the crucial need for supplemental irrigation in these locations. Moreover, in Cruzeiro do Sul, Acre, the lowest annual water deficit, 23--237 mm, occurred among the locations evaluated from May to September, and regular supplemental irrigation is also recommended at this location. Because coffee cultivation in the state of Acre is located mainly on small rural properties, an economic analysis is recommended since the costs of implementing irrigation systems on family properties can be high. Among the locations evaluated, the municipality of Tarauacá, Acre, presented the largest annual water surpluses for coffee (*Coffea canephora*) in medium-textured soil, with values decreasing from 1,175 to 646 mm, with cultivation coefficients of 0.9 and 1.5, respectively.

7 THANKS

The meteorological and environmental database collected from the climatological network of the National Institute of Meteorology (INMET) is available on the worldwide-wide website.

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