ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.29, n.1, e281191, 2025
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v29n1e281191

ORIGINAL ARTICLE

Water requirement satisfaction index for coffee (*Coffea canephora*) crops in Western Amazon[1]

Índice de satisfação da necessidade de água para a cultura do *Coffea canephora* na Amazônia Ocidental

Jefferson V. José[2*], Lívia B. Pereira[3], Moisés D. Souza[4], Kelly N. Leite[2], Otávio N. A. Santos[5] & Lucas C. Santos[6]

[1] Research developed at Universidade Federal do Acre, Cruzeiro do Sul, AC, Brazil
[2] Universidade Federal do Acre, Cruzeiro do Sul, AC, Brazil
[3] Instituto Agronômico, Campinas, SP, Brazil
[4] Universidade do Estado do Mato Grosso, Tangará da Serra, MT, Brazil
[5] Universidade Estadual do Sudoeste da Bahia, Vitória da Conquista, BA, Brazil
[6] Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina, MG, Brazil

HIGHLIGHTS:

Air temperature was the only climate variable restrictive to coffee crops.
Water Requirement Satisfaction Index is more efficient in quantifying climate risk than monthly data.
The region has water limitation only during the coffee flowering stage.

ABSTRACT: Water balance is a tool that has various applications in agriculture, including assessing whether an environment is suitable for growing a specific crop by providing information on how water resources function in the system. This information is essential for determining whether the available water satisfies the crop's demand. Thus, the objective of this work was to calculate the water balance of Typic Hapludults for growing coffee (*Coffea canephora*) crops in Cruzeiro do Sul, Acre, Brazil, using a 36-year historical series to assess the potential and limitation of the crop according to the water availability. The results showed that coffee crops are, in general, suitable for growing in the study region. Water deficit and water surplus periods are well-defined, from April to August and September to March, respectively. Flowering was the only stage of coffee crops that coincides with the water deficit period in the region; thus, irrigation is necessary to prevent compromising this stage and fruit development. The Water Requirement Satisfaction Index (WRSI), calculated on a monthly basis, indicates a low climate risk for coffee crops in the region. However, when calculated on a daily basis, the WRSI shows a medium to high climate risk for coffee crops in several periods. The WRSI proved to be an adequate tool for assisting in decision-making regarding the adoption of irrigation.

Key words: water availability, irrigation, crop water use

RESUMO: O balanço hídrico é uma ferramenta com diversas aplicações na agricultura, incluindo a avaliação da adequação de um ambiente para o cultivo de uma determinada cultura, através da compreensão de como os recursos hídricos operam no sistema. Esta informação é vital para determinar se a água disponível satisfaz a necessidade da cultura. Assim, objetivou-se calcular o balanço hídrico em um Argissolo Vermelho-Amarelo para o cultivo de *Coffea canephora* no município de Cruzeiro do Sul, Acre, utilizando uma série histórica de 36 anos para avaliar o potencial e as restrições da cultura de acordo com a água disponível. Os resultados mostraram que, de forma geral, o cultivo de *Coffea canephora* é adequado para a região de estudo. Os períodos de déficit hídrico e de excesso de água são bem definidos, ocorrendo de abril a agosto e de setembro a março, respectivamente. Verificou-se que apenas a fase de floração do cafeeiro coincide com o período de déficit hídrico na região, exigindo assim irrigação para evitar comprometer essa etapa do desenvolvimento do fruto. Em relação ao Indice de Satisfação da Necessidade de Água (ISNA), observou-se que, quando calculado em uma escala mensal, indica baixo risco climático para o cultivo de *Coffea canephora* na região. No entanto, quando calculado em uma escala diária, o ISNA indica risco climático médio a alto para o cultivo durante vários períodos. O ISNA mostrou ser uma ferramenta adequada para a tomada de decisão quanto à adoção de técnicas de irrigação.

Palavras-chave: disponibilidade hídrica, irrigação, uso de água da cultura

• Ref. 281191 – Received 07 Dec, 2023
* Corresponding author - E-mail: jfvieira@hotmail.com.br
• Accepted 16 Jul, 2024 • Published 30 Jul, 2024
Editors: Geovani Soares de Lima & Carlos Alberto Vieira de Azevedo

Introduction

Brazil is the largest coffee-growing country in the word, with the highest production and export (Volsi et al., 2019). The area grown with coffee in Brazil (*Coffea arabica* and *Coffea canephora*) was estimated in 2.25 million hectares in 2024, 421,960 hectares of this area with *C. canephora*. Acre is the second-largest coffee producing state in the North region of Brazil, reaching an annual production of 2,858 Mg and 993 ha grown with *C. canephora* in 2023 (CONAB, 2024). The suitability of the state of Acre for *C. canephora* crops is due to its favorable agroclimatic characteristics for the development and harvest of this species compared to *Coffea arabica*.

Estimates of climate variables have become important for planning and management of water resources in the state of Acre. Specifically for coffee crops, these estimates provide information about water requirement of certain areas and is a base for delimitation and identification of places with greater potential for this crop, which is relevant in the producers' decision making and generate higher agricultural efficiency. According to Pezzopane et al. (2010), studies on climate variables can determine the more suitable areas for coffee crops in a region. The Water Requirement Satisfaction Index (WRSI) is one of the key tools for describing agroclimatic characteristics and has been utilized in various agrometeorological studies, including Masupha & Moeletsi (2020), Boult et al. (2020), and Turner et al. (2022). WRSI is determined by the relationship between real evapotranspiration and reference evapotranspiration. This index is determined based on assessing the climatic water balance.

Focusing in supporting the expansion of coffee crops and contributing to reducing the gap in agronomic scientific research in the state of Acre, the objective of this work was to calculate the water balance of Typic Hapludults for growing coffee (*Coffea canephora*) crops in Cruzeiro do Sul, Acre, Brazil, using a 36-year historical series to assess the potential and limitation of the crop according to the water availability.

Material and Methods

The study area was the region of Cruzeiro do Sul, which is located in the Alto Juruá Hydrographic Basin, western state of Acre, Brazil (-7.61 S and -72.68 W, and altitude of 220 m).

The predominant climate in the region is Af, tropical without a well-defined dry season, according to the Köppen & Geiger classification (Alvares et al., 2013). The driest period in Cruzeiro do Sul lasts only three months (June, July, and August), and the rainy season begins in September. The mean annual temperature is 25.86 °C, with maximum of 32.7 °C and minimums above 21 °C (Sousa, 2020).

The dataset used in this research was from the conventional meteorological station installed in Cruzeiro do Sul, which belongs to the Brazilian National Institute of Meteorology (INMET; http://www.inmet.gov.br/portal). A 36-year historical series (1980 to 2016) was evaluated. Some data were missing due to record failures, as it is a relatively extensive series (Table 1).

The missing data of solar radiation were estimated using the Angstrom-Prescot and Bristow-Campbell methodologies, using data of radiation and daily temperature amplitude. Gaps due to missing data of the other variables were filled using the HidroWeb database of the Brazilian National System of Information on Water Resources; the Brazilian National Water Agency and Basic Sanitation database; the automatic station of the INMET in Cruzeiro do Sul; the ERA5 Daily satellite of the Google Earth Engine satellite catalog; the database developed by Xavier et al. (2015); and the Kalman filter.

The meteorological variables evaluated were: temperature (mean, maximum, and minimum), mean relative air humidity, insolation, solar radiation, wind speed, rainfall depth, and reference evapotranspiration (ETo). The Penman-Monteith-FAO method was used to estimate the reference evapotranspiration.

Crop evapotranspiration (ETc) was calculated by the product between crop coefficient (Kc) and ETo. The Kc values used for the coffee crops were 0.89, 1.05, and 0.89 for the initial, intermediate, and final stages, respectively, as recommended by Costa et al. (2019).

The easily available water of 75.84 mm was determined based on the available water value (1.58 mm cm^{-1}) provided by EMBRAPA (2020). The root system depth (Zr) adopted for the coffee crops was 80 cm, and the soil water availability factor (f) was 0.6. The soil used to represent the region was Typic Hapludult (USDA, 2014).

Daily ETc, rainfall depth, and easily available water were used to elaborate the sequential and normal climatic water balance (1980 to 2016) by the Thornthwaite & Mather method, which provided the real evapotranspiration (ETr), water deficiency, water surplus, and soil water storage.

Daily and monthly WRSI were determined considering the relationship between ETr and ETc. Values of 0.65 to 1 indicate

Table 1. Meteorological data from the conventional meteorological station of the Brazilian National Institute of Meteorology (INMET) in Cruzeiro do Sul, of Cruzeiro do Sul, Acre, Brazil, and data added to fill gaps due to missing data.

Variable	Missing data (%)	Added data (%)						
		Hidroweb	Auto	Satellite	Xavier	BC	Angs	Kalman
Maximum air temperature	9.12	-	2.52	4.31	2.27	-	-	-
Minimum air temperature	60.19	-	2.96	0.79	56.42	-	-	-
Mean air temperature	6.11	-	2.54	0.90	2.65	-	-	-
Mean relative air humidity	34.13	-	2.52	-	30.89	-	-	0.72
Wind speed	20.59	-	2.48	0.65	17.44	-	-	-
Global solar radiation	100	-	-	-	-	11.69	88.30	-
Solar insolation	11.69	-	-	-	-	-	-	-
Rainfall depth	4.52	0.79	2.48	1.23	-	-	-	-

Total number of data - 108120; Total number of missing data - 32848; Xavier - Xavier et al. (2015); Satellite - Satellite ERA5 Daily; Auto - Cruzeiro do Sul automatic station (A108); BC - Bristow-Campbell; Angs - Angstron-Prescot; Hidroweb - http://www.snirh.gov.br/hidroweb/; Kalman - Kalman filter low climate risk, 0.45 to 0.65 indicate medium climate risk, and values lower than 0.45 indicate high climate risk for coffee (*Coffea canephora*) crops in the region of Cruzeiro do Sul, Acre, Brazil (Bergo & Bardales et al., 2018).

The data were processed using the program R Statistical® to calculate the water balance. ETo was estimate using the program REF-ET.

Results and Discussion

The mean annual rainfall depth in Cruzeiro do Sul, Acre, Brazil, was 2,152.6 mm. The highest annual rainfall depth was found for 1989, with 2749.6 mm, and the lowest was found for 1985, with 1591.8 mm. According to González et al. (2015), a rainfall depth range of 1200 to 1800 mm is favorable for coffee (*Coffea canephora*) crops, as it is associated with higher yields. The maximum monthly rainfall depth was found for September 1990, 492.8 mm, and the minimum for June 2012, 3.3 mm. Mean monthly rainfall depth was 179.9 mm (Figure 1A). The boxplot shown in Figure 2A, clearly illustrates that rainfall depths considerably decrease between April and July and subsequently increase in August. The results indicate that the rainy season spans from September to March. January

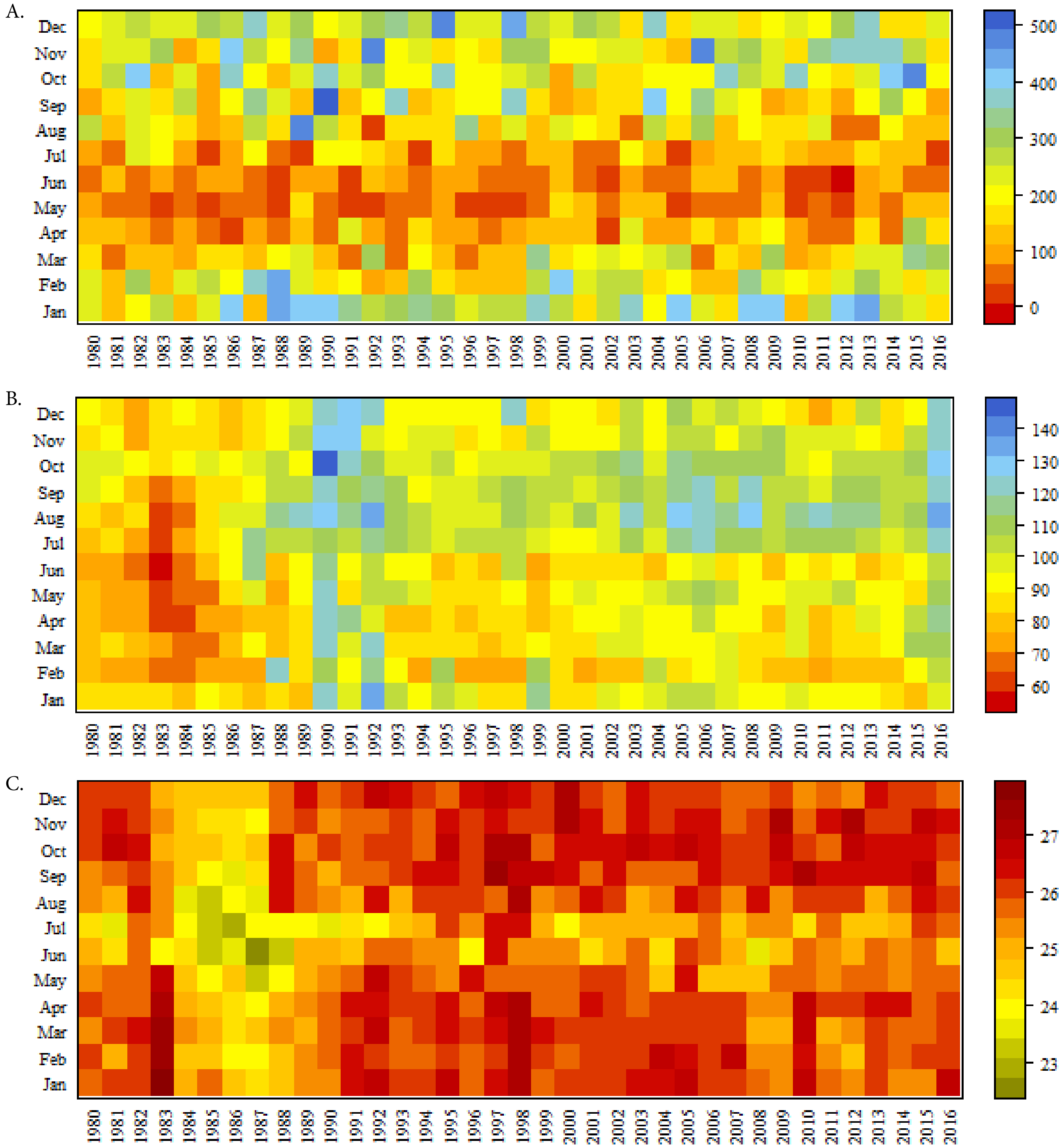


Figure 1. Monthly rainfall depth (A), reference evapotranspiration (B), and air temperature (C) from 1980 to 2016 in Cruzeiro do Sul, Acre, Brazil

and October exhibited the most significant variability in rainfall depths (Figure 1A).

The mean daily reference evapotranspiration was 3.09 mm, and the mean monthly reference evapotranspiration was 93.96 mm. The mean annual evapotranspiration was 1134.7 mm, with the highest value recorded in 1990 (1463.47 mm) and the lowest in 1983 (842.16 mm). The highest evapotranspiration rates were found between 1987 and 1992, and from 2005 to 2015. Evapotranspiration rates in 1990 were particularly high throughout the year. The evapotranspiration index increased from July to December during the period from 2005 to 2015 (Figure 1B).

The mean annual air temperature in Cruzeiro do Sul was 25.6 °C, ranging from 25 to 26 °C (Figure 1C). The highest annual temperature was 26.5 °C, in 1998, and the lowest 23.9 °C, in 1987. Temperatures ranged from 22.7 to 25.5 °C during the period from 1984 to 1987. According to Kath et al. (2019), temperatures above 20.5 °C and below 25.1 °C is suitable coffee crops. The annual mean temperature exceeded 25.1 °C in 89.1% of the analyzed period and, on average, 43% of the analyzed days had temperatures above 26 °C.

In the 36-year historical series, water deficits and surpluses were evenly distributed across the years. The longest water deficit periods occurred in 2010-2011 and 2012-2013; 2012 had the highest water deficit (285.82 mm). The most significant water surplus periods occurred in 2000-2001 and 2013-2014.

Daily soil water storage remained relatively constant, but decreased from late April to late July. From August onwards, water storage began to rise, reaching maximum capacity and stabilizing again. This decrease in storage coincides with reduced rainfall depths and increased evapotranspiration. Rainfall depths and evapotranspiration started to increase again at late August. Under normal climate conditions, the first rains of the season usually occur in August or September, triggering the flowering of coffee plants. In this case, rainfall depths begin to normalize in August, indicating that the coffee flowering would not be affected.

Figure 2C shows that water deficits occurred from April to August, starting in 1985, and did not occur in any month of 2016. The monthly boxplot (Figure 2D) also shows that the period of greatest water deficit exhibits higher variability in May, June, and July. Additionally, the soil water deficit

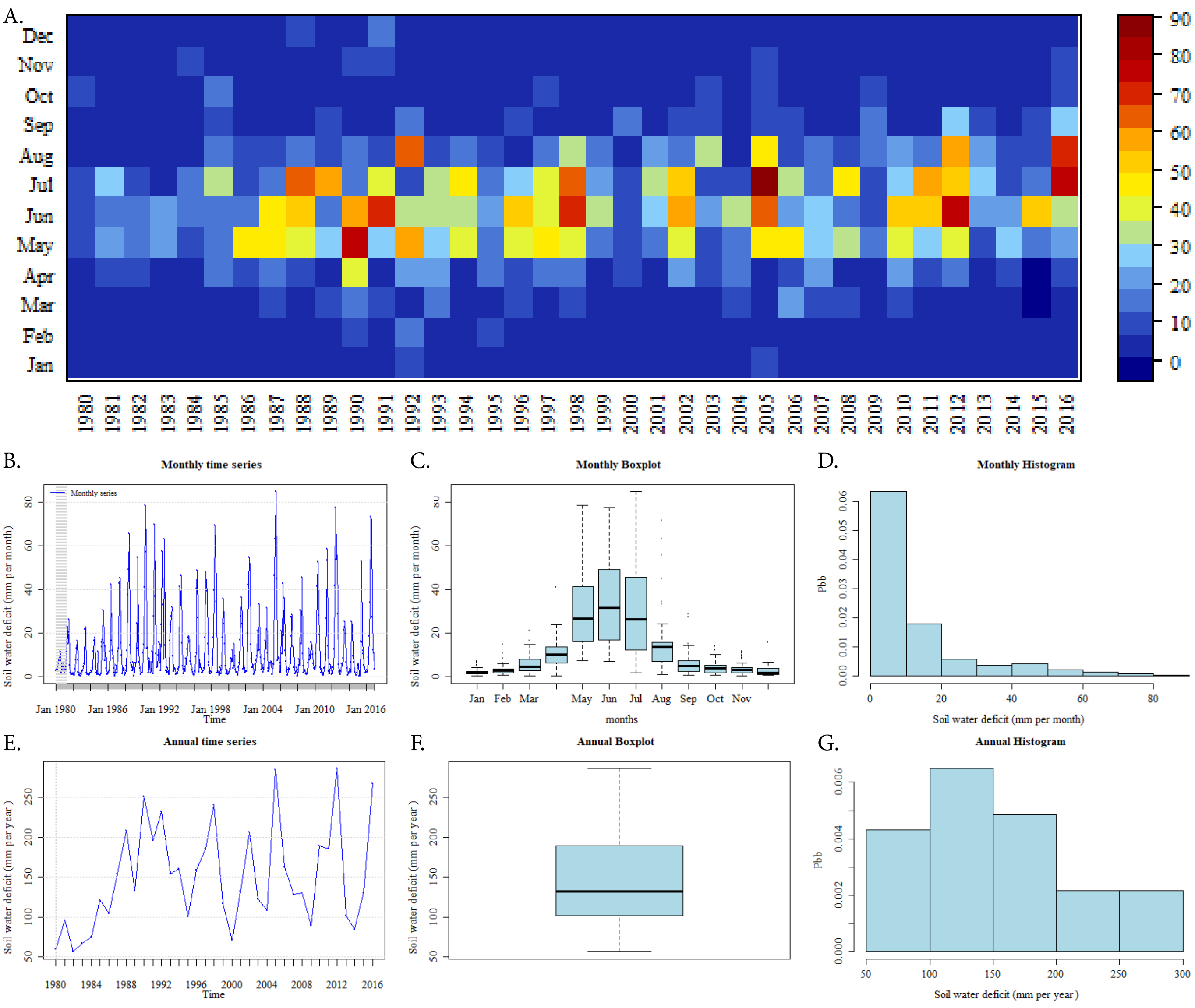


Figure 2. Monthly and annual soil water deficit from 1980 to 2016 in Typic Hapludults for coffee crops in Cruzeiro do Sul, Acre, Brazil

starts in April, and the period of water surplus begins in mid-September. Bergo & Bardales (2018) reported that the main coffee flowering phase occurs 5 to 8 days after a rainfall of 5 mm to 15 mm, between late July and early August. This time interval coincides with the period of water deficit in the region.

The annual water deficit exceeded 200 mm in seven years, with the highest peak in 2012 (285.92 mm) (Figure 2E). Water deficits above 200 mm are considered marginal in terms of water suitability for coffee crops, according to Martins et al. (2018).

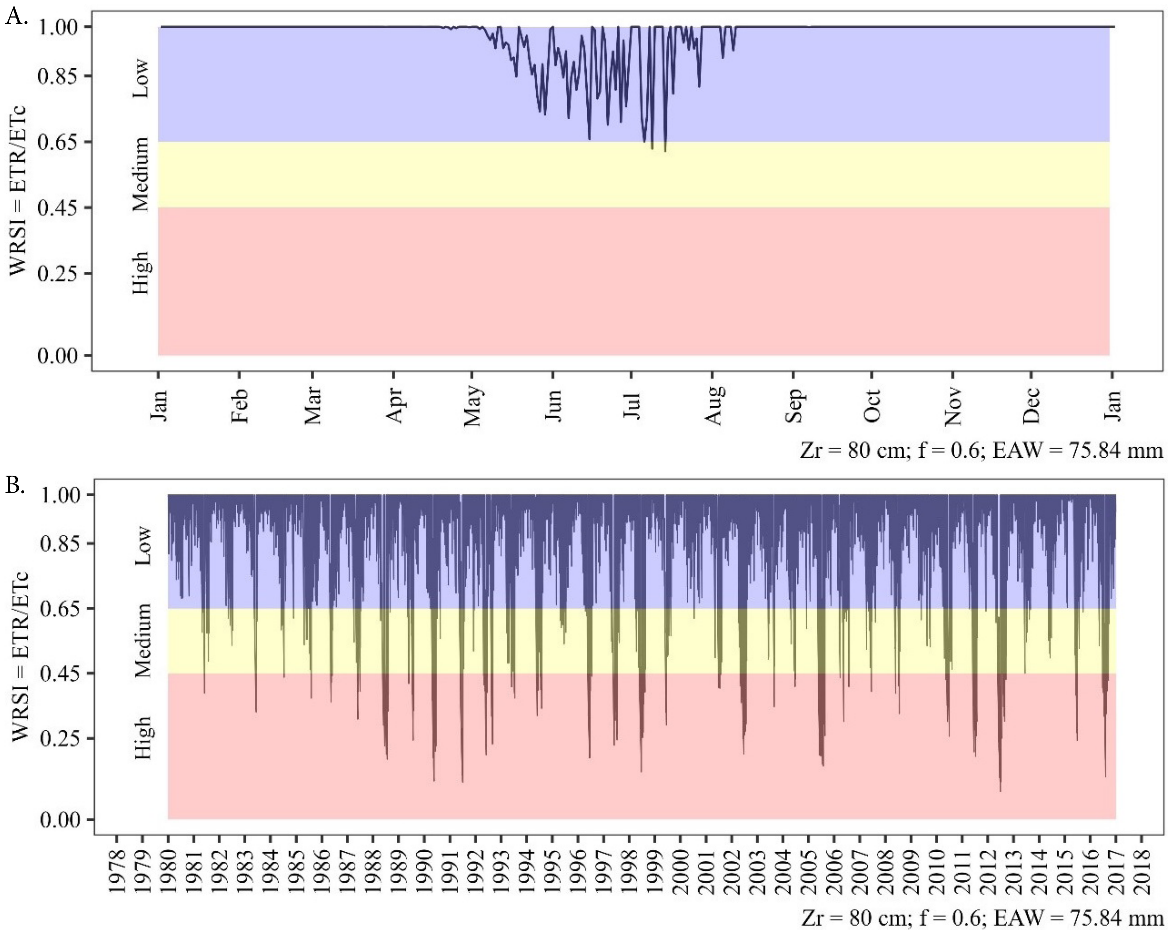
During the water deficit period, mean annual air temperatures ranged from 25 °C, reaching 26 °C in August, when soil moisture begins to increase again. Contrastingly, water surplus period was found under mean annual air temperatures between 26.1 and 27.1 °C. According to Bergo & Bardales (2018), temperatures exceeding 26 °C, combined with drought periods, during coffee flowering can lead to abortion of flowers and formation of sterile flowers, reducing crop productivity.

During the dry season, water deficit can lead to partial or total closure of stomata throughout the day, reducing stomatal conductance and internal CO_2 concentration, thus compromising the photosynthetic rate (Custodio et al., 2022). These effects are worse when high air temperatures coincide with low water availability, causing stomatal closure, significantly reducing photosynthesis rates, growth, and coffee yield (Ronchi & Da Matta, 2007). According to Adhikari et al. (2020), Robusta coffee is sensitive to the dry seasons exceeding 3 to 4 months due to high evapotranspiration. Furthermore, coffee has been classified as a plant species highly sensitive to climate changes that occur over time (Da Matta et al., 2019), and the sensitivity of this species to climate variables changes, depending on the phenological stage of the plant (Koh et al., 2020).

According to Navarro-Serrano et al. (2020), the spatial distribution of air temperature is controlled by altitude; in this sense, Kath et al. (2020) highlights that there are currently no estimates of ideal minimum and maximum temperatures for the flowering and growth stages of *C. canephora*. Kath et al. (2020) focused on determining the ideal temperature for coffee (*C. canephora*) crops and found that this species is more sensitive to temperature than previously thought, highlighting that its productive potential can considerably decrease as temperatures increase due to climate change.

Sousa & Oliveira (2018) assessed the temperature and water suitability for coffee (*C. canephora*) crops in Cruzeiro do Sul and found little climate risk for non-irrigated crops. Therefore, air temperature alone is not a restrictive factor for coffee (*C. canephora*) crops in Cruzeiro do Sul; however, when combined with other unfavorable variables, it becomes a limiting factor, necessitating some actions to make this crop viable.

According to the monthly Water Requirement Satisfaction Index (WRSI), there was a low climate risk (> 0.65) for coffee crops (1980 to 2016) (Figure 3A). Bergo's & Bardales (2018)



Zr – Depth of the root system; EWA – Easily available water; f – Available factor

Figure 3. Monthly (A) and daily (B) water requirement satisfaction index (WRSI) for coffee crops in Typic Hapludults in Cruzeiro do Sul, Acre, Brazil, from 1980 to 2016

found mean monthly WRSI between 0.85 and 1.00 for the flowering stage of coffee crops grown under the climate conditions of Cruzeiro do Sul (1950 to 2000).

Daily WRSI showed reveal multiple peaks, meaning a medium to high risk of climatic limitations for coffee crops, mainly when the WRSI falls below 0.45 (Figure 3B). This situation occurred 834 times within the historical series, representing 6.17% of the total data. Consequently, coffee crops might have faced water limitations in several years, potentially compromising yields. Monthly WRSI calculations may hide actual fluctuations, emphasizing the necessity of daily analysis.

The rest and senescence stages of coffee branches in May and June are not critical for the crop. No water limitations occur during the expansion and fruit formation (October-January) and fruit ripening stages (February-April), as shown by the low and medium WRSI, respectively. Ronchi & Damatta (2007) reported that water deficit affects coffee crops during two reproductive stages: flowering and fruit formation. Greater vigor, growth, and yield of coffee plants are expected in irrigated cropping systems compared to rainfed cropping systems (Byrareddy et al., 2020). Considering the phenology of coffee plants, a period of water stress after each irrigation helps to break the dormancy of floral buds, triggering flowering uniformly and initiating fruit development, which is crucial for achieving high yields (Amarasinghe et al., 2015). Thus, irrigation is only necessary during the flowering stage for an optimal plant development, since the fruit formation stage does not coincide with water limitations.

Conclusions

1. The climate conditions of Cruzeiro do Sul, Acre, Brazil, revealed water and temperature suitability for coffee (*Coffea canephora*) crops.

2. Soil water storage decreases from late April to late July. From August onwards, water storage begins to increase again, reaching maximum capacity and stabilizing.

3. Although complementary irrigation is recommended for coffee crops in Cruzeiro do Sul, the water balance drawn from the series of meteorological data showed that the water deficit is temporary and, thus, this crop can be grown without irrigation, as long as the coffee plants have some tolerance to water deficit.

4. The Water Requirement Satisfaction Index proved to be an adequate tool for decision-making regarding the adoption of irrigation techniques.

Contribution of authors: Jefferson V. José: Conceptualization, Methodology, Data curation, Writing - review & editing; Lívia B. Pereira: Formal analysis, Methodology, Writing - review & editing; Moisés D. Souza: Methodology & Formal analysis; Kelly N. Leite: Formal analysis, Writing - review & editing; Otávio N. Almeida: Formal analysis & Supervision; Lucas C. Santos: Methodology, Formal analysis & Supervision.

Supplementary documents: There are no supplementary sources.

Conflict of interest: The authors declare no conflict of interest.

Financing statement: There was no funding for this research.

Literature Cited

Adhikari, M.; Isaac, E. L.; Paterson, R. R. M.; Maslin, M. A. A review of potential impacts of climate change on coffee cultivation and mycotoxigenic fungi. Microorganisms, v.8, p.16-25, 2020. https://doi.org/10.3390/microorganisms8101625

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Amarasinghe, U. A.; Hoanh, C. T.; D'haeze, D.; Hung, T. Q. Toward sustainable coffee production in Vietnam: More coffee with less water. Agricultural Systems, v.136, p.96-105, 2015. https://doi.org/10.1016/j.agsy.2015.02.008

Bergo, L. C; Bardales, G. N. Zoneamento edafoclimático para o cultivo do Café Canéfora (*Coffea canéfora*) no Acre. 1.ed. Brasília: Embrapa, 2018.

Boult, V. L.; Asfaw, D. T.; Young, M.; Maidment, R.; Mwangi, E.; Ambani, M.; Waruru, S.; Otieno, G.; Todd, M. C.; Black, E. Evaluation and validation of TAMSAT-ALERT soil moisture and WRSI for use in drought anticipatory action. Meteorological Applications, v.27, p.19-59, 2020. https://doi.org/10.1002/met.1959

Byrareddy, V.; Kouadio, L.; Kath, J.; Mushtaq, S.; Rafiei, V.; Scobie, M.; Stone, R. Win-win: Improved irrigation management saves water and increases yield for robusta coffee farms in Vietnam. Agricultural Water Management, v.241, e106350, 2020. https://doi.org/10.1016/j.agwat.2020.106350

CONAB – Companhia Nacional de Abastecimento. Acompanhamento da Safra Brasileira de Café: Boletim café maio, 2024. Available on: <https://www.conab.gov.br/info-agro/safras/cafe>. Acessed on: Jun. 2024.

Costa, J. O.; Coelho, R. D.; Barros, T. H. S.; Fraga Júnior, E. F.; Fernandes, A. L. T. Leaf area index and radiation extinction coefficient of a coffee canopy under variable drip irrigation levels. Acta Scientiarum Agronomy, v.41, p.1-8, 2019. https://doi.org/10.4025/actasciagron.v41i1.42703

Custodio, A. M.; de Menezes, S. P. E.; Santos, T. R. D.; Lourenço, L. L.; Avila, R. G.; da Silva, A. R.; Silva, F. G. Seasonal Variation in Physiological Traits of Amazonian *Coffea canephora* Genotypes in Cultivation Systems with Contrasting Water Availability. Agronomy, v.12, e3197, 2022. https://doi.org/10.3390/agronomy12123197

DaMatta, F. M.; Rahn, E.; Läderach, P.; Ghini, R.; Ramalho, J. C. Why could the coffee crop endure climate change and global warming to a greater extent than previously estimated?. Climatic Change, v.152, p.167-178, 2019. https://doi.org/10.1007/s10584-018-2346-4

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Estimativa de água disponível dos solos do Brasil. 1.ed. Rio de Janeiro: Embrapa Solos, 2020

González, B. C.; Díaz, P. A.; Espinosa, R. R.; Alonso, M. G. M.; Nuñez, V. R. Influence of rainfall on the yield of Coffea canephora Pierre ex Froehner cultivated in cambisol soils of the eastern region of Cuba. Cultivos Tropicales, v.36, p.21-27, 2015.

Kath, J.; Byrareddy, V. M.; Craparo, A.; Nguyen-Huy, T.; Mushtaq, S.; Cao, L.; Bossolasco, L. Not so robust: Robusta coffee production is highly sensitive to temperature. Global Change Biology, v.26, p.3677-3688, 2020. https://doi.org/10.1111/gcb.15097

Koh, I.; Garrett, R.; Janetos, A.; Mueller, N. D. Climate risks to Brazilian coffee production. Environmental Research Letters, v.15, e104015, 2020. https://doi.org/10.1088/1748-9326/aba471

Martins, L. D.; Eugenio, F. C.; Rodrigues, W. N.; Brinati, S. V. B.; Colodetti, T. V.; Christo, B. F.; Olivas, D. B. L.; Partelli, F. L.; Amaral J. F. T.; Tomaz, M. A.; Ramalho, J. D. C. Santos, A. R. Adaptation to long-term rainfall variability for robusta coffee cultivation in Brazilian Southeast. American Journal of Climate Change, v.7, p.487-504, 2018. https://doi.org/10.4236/ajcc.2018.74030

Masupha, T. E.; Moeletsi, M. E. The use of Water Requirement Satisfaction Index for assessing agricultural drought on rain-fed maize, in the Luvuvhu River catchment, South Africa. Agricultural Water Management, v.237, p.106-142, 2020. https://doi.org/10.1016/j.agwat.2020.106142

Navarro-Serrano, F.; López-Moreno, J. I.; Azorin-Molina, C.; Alonso-González, E.; Aznarez-Balta, M.; Buisán, S. T.; Revuelto, J. Elevation effects on air temperature in a topographically complex mountain valley in the Spanish Pyrenees. Atmosphere, v.11, e656, 2020. https://doi.org/10.3390/atmos11060656

Pezzopane, J. R. M.; Castro, F. S.; Pezzopane, J. E. M.; Bonomo, R.; Saraiva, G. S. Zoneamento de risco climático para a cultura do café Conilon no Estado do Espírito Santo. Revista Ciência Agronômica, v.41, p.341-348, 2010. https://doi.org/10.1590/S1806-66902010000300004

Ronchi C. P.; DaMatta F. M. Aspectos fisiológicos do café conilon. In: Ferrão, R. G.; Fonseca, A. F. A.; Bragança, S. M.; Ferrão, M. A. G.; Muner, L. H. de (eds.). Café Conilon. Vitória, Seag/Incaper. v.1, p.92-119, 2007.

Sousa, J. W. de. Características climáticas do município de Rio Branco, Acre, período de 1990-2019. Scientia Naturalis, v.2, p.723-740, 2020.

Sousa, J.; Oliveira, P. Risco climático para o café Conilon (Coffea canephora) nos municípios de Rio Branco, Tarauacá e Cruzeiro do Sul, AC. Revista Brasileira de Ciências da Amazônia, v.7, p.31-40, 2018. https://doi.org/10.47209/2317-5729.v.7.n.2.p.31-40

Turner, W. A.; Husak, G.; Funk, C.; Roberts, D. A.; Jones, C. An improved climatological forecast method for projecting end-of-season Water Requirement Satisfaction Index. Journal of Hydrometeorology, v.23, p.1281-1295, 2022. https://doi.org/10.1175/JHM-D-21-0184.1

United States. Soil Survey Staff. Keys to Soil Taxonomy (12th ed.) USDA NRCS. 2014. Available at: <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Jun 19, 2024.

Volsi, B.; Telles, T. S.; Caldarelli, C. E.; Camara, M. R. G. D. The dynamics of coffee production in Brazil. PloS one, v.14, e0219742, 2019. https://doi.org/10.1371/journal.pone.0219742

Xavier, A. C.; King, C. W.; Scanlon, B. R. Daily gridded meteorological variables in Brazil (1980-2013). International Journal of Climatology, v.36, p.2644-2659, 2015. https://doi.org/10.1002/joc.4518