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ORIGINAL ARTICLE

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Probable rainfall contribution to coffee water demand in Uberlândia, Minas Gerais state, Brazil

Contribuição da precipitação provável para a demanda hídrica do cafeeiro em Uberlândia, Minas Gerais, Brasil

ABSTRACT: The occurrence, distribution of rainfall and the knowledge of crop water demand are essentials to irrigation planning. Thus, the determination of probable rainfall can contribute substantially to suitable irrigation projects. This work aimed to determine the probable rainfall for Uberlândia, Minas Gerais state, Brazil, in order to evaluate its contribution to coffee water demand. Daily precipitation data from 1975 to 2010 were summed in a 30-day period (monthly) and applied to Gamma distribution. The probable rainfall was estimated to different probability levels (%): 40, 45, 55, 65, 75, 85, and 95. With 75% of probability of exceedance (considered suitable to irrigation purposes) the probable rainfall in Uberlândia overcomes the coffee evapotranspiration only in December and January, suggesting a supplementary irrigation for vegetative growth and fructification periods (from October to April-May). During the entire dry-season the probable rainfall does not overcome the coffee evapotranspiration.

RESUMO: *A ocorrência, distribuição de chuvas e o conhecimento das necessidades hídricas das culturas são essenciais para o planejamento da irrigação. Assim, a determinação da precipitação provável pode contribuir substancialmente em projetos de irrigação. Este trabalho foi realizado objetivando-se determinar a precipitação provável de Uberlândia, Minas Gerais, Brasil, para avaliar sua contribuição para a demanda hídrica da cultura do café. Dados de precipitação diários de 1975 a 2010 foram totalizados em períodos mensais e aplicados à distribuição Gama. A precipitação provável foi estimada em diferentes níveis de probabilidade de excedência (%): 40, 45, 55, 65, 75, 85 e 95. Com 75% de probabilidade de excedência (nível considerado adequado para projetos de irrigação), a precipitação provável supera a evapotranspiração do cafeeiro somente em dezembro e janeiro, sugerindo irrigação suplementar para os períodos de crescimento vegetativo e frutificação do cafeeiro. Durante toda a estação seca, a precipitação provável não supera a evapotranspiração do cafeeiro.*

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1 Introduction

Brazil is the major world coffee producer (*Coffea arabica* and *Coffea canephora*). For 2014, a production is estimated between 46 and 50 million bags. Uberlândia is located in the Cerrado Biome, Triangulo Mineiro region – currently an important region in the Brazilian agribusiness. In this region, the coffee has been cultivated on 27,000 hectares with production estimated at 2014 of 6 million of bags and productivity of 36 bags ha^{-1}. Unquestionably, the use of irrigation on Cerrado coffee areas is one of the practices that contribute to increase the productivity and quality of crop (Matiello et al., 2010). In Brazil, irrigated coffee crops cover around 300,000 ha, concentrated for the most part in the Triangulo Mineiro region, considered an irrigation-dependent and responsive area (Matiello et al., 2010).

The adoption of irrigation practice in a given region requires basic studies such as: occurrence and distribution of natural rainfall and the knowledge of the crop water requirement. Based on the spatial-temporal analysis of water requirements of the coffee crop performed for Minas Gerais state, Brazil, the mean annual coffee evapotranspiration is between 1,100 and 1,200 mm (Lemos Filho et al., 2010). The historical mean annual rainfall (from 1975 to 2010) for Uberlândia is 1,472 mm, but 86% is concentrated during the wet-season (Ribeiro et al., 2013).

The probable rainfall is defined as the minimum precipitation expected for a given period in a given probability level (called probability of exceedance) (Bernardo et al., 2005). The knowledge of the probable rainfall may play an important role in a suitable implementation of irrigation systems, and also contribute to rainfall-dependent activities such as soil tillage, sowing, liming, fertilization, pesticide application, and harvesting.

The probability of exceedance considered suitable in irrigation projects is 75% (Bernardo et al., 2005), and the probable rainfall estimated has been performed based on some distribution models such as Gamma, Normal, Log-Normal 2 and 3 parameters, among others (Fietz et al., 1998; Fietz et al., 2008; Martins et al., 2010; Ribeiro et al., 2007; Ribeiro & Avanzi, 2010; Soccol et al., 2010).

This work was carried out aiming to estimate the 30 - day probable rainfall at different levels of probability of exceedance for Uberlândia, Minas Gerais state, Brazil, in order to evaluate its contribution to coffee water needs, adding to irrigation planning.

2 Materials and Methods

This work was carried out from daily rainfall data acquired from the Brazilian National Water Agency – ANA (ANA, 2012) from a weather stationlocatedat18°59’18’’S and 48°11’25’’W, Uberlândia, Minas Gerais state, Brazil, climate Aw (Köppen’s classification) and altitude of 800m. The data were summed in a 30-dayperiod (monthly) from 1975 to 2010 (36 years) and applied to Gamma distribution.

Gamma model is defined by the following integral equations (1 to 3) (Lanna, 2001):

$$\Gamma(\alpha) = \int_0^{\infty} x^{\upsilon-1} e^{-x} dx, \upsilon > 0 \quad (1)$$

$$P(\alpha, x) = \int_0^{x} x^{(\upsilon-1)} e^{-x} dx \quad (2)$$

$$P(\alpha, x) = \int_0^{x} x^{(\upsilon-1)} e^{-x/\beta} dx \quad (3)$$

The probability density function can be expressed by equation 4 (Botelho, 1989):

$$FDP: f(x) = \frac{1}{\beta^{\gamma} \cdot \tilde{A}(\gamma)} \cdot x^{\gamma-1} \cdot e^{-x/\beta}, 0 < x < \infty \quad (4)$$

With $\gamma > 0$, $\beta > 0$, $\Gamma(\gamma) > 0$, where γ is dimensionless parameter, β is scale parameter and x is random variable (rainfall).

The ν and β parameters can be estimated by Equations 5 and 6, respectively:

$$\gamma = \frac{\overline{x}^2}{S_x^{\,2}} \quad (5)$$

$$\beta = \frac{S_x^{\,2}}{\overline{x}} \quad (6)$$

Where $\overline{x}$ and S_x are the average and standard deviation of dataset, respectively.

The Qui-Square Test (λ^2) ($\alpha = 0.05$) was used to evaluate the suitability of Gamma distribution, considering the degrees of freedom as being the number of classes minus one (Ferreira, 2005). Once the Gamma distribution was considered adequate, the 30-day (monthly) probable rainfall was estimated at different probability levels (%): 40,45, 55, 65, 75, 85, and 95.

To estimate the coffee evapotranspiration (ETc) were used the evapotranspiration coefficient values (Kc) obtained by Santinato et al. (1996) (Table 1) for different conditions.

For each condition (Table 1), the coffee evapotranspiration (ETc) was calculated for each month by Equation 7:

$$ETc = ETo \times Kc \quad (7)$$

Where:
ETc: coffee evapotranspiration (mm), for each condition and month; ETo: reference crop evapotranspiration (mm), for each month; EP: monthly evaporation estimated by Pan Evaporation Method; 0.75 = Pan’s coefficient. ETo = EP × 0.75. The Pan’s coefficient adopted corresponds to a medium value based on pan type and environment conditions (Allen et al., 1998).

Table 1. Evapotranspiration coefficients (Kc) for coffee crop obtained under different conditions.

Tabela 1. Coeficientes de evapotranspiração (Kc) do cafeeiro em diferentes condições.

Condition	Age (yrs)	Coffee arrangement		Plants ha^{-1}	Kc
		Interrow	Row		
I	> 3	> 3.0	> 1.0	2,500	1.0
II		1 to 2	0.5 to 1.0	13,333	1.3
III	1 to 3	> 3.0	> 1.0	2,500	0.8
IV		1 to 2	0.5 to 1.0	13,333	1.1
V	0 to 1	> 3.0	> 1.0	2,500	0.6
VI		1 to 2	0.5 to 1.0	13,333	0.9

Source: Santinato et al. (1996).

The contribution of rainfall to crop water needs was performed by comparison of the monthly ETc calculated for each condition (as showed in Table 1) with probable rainfall at different levels of probability of exceedance: 40, 45, 55, 65, 75, 85, and 95%.

3 Results and Discussion

The Gamma distribution, evaluated by the λ^2 test, was considered suitable for all months (calculated $\lambda^2 <$ standard λ^2) (Table 2). In many probability-frequency-rainfall distribution studies the Gamma distribution model has been considered more adequate (Fietz et al., 1998; Araújo et al., 2001; Ribeiro et al., 2007; Martins et al., 2010; Ribeiro & Avanzi, 2010; Soccol et al., 2010). The average probability of historical monthly rainfall to be overcome was 40%. Considering the dry-season (April to September) the probability level was 35%, and during the wet-season (October to March) it was 44% (Table 2).

The historical monthly average rainfall in Uberlândia (Figure 1a) has a probability of exceedance of 40%, in other words, the probability of historical monthly average rainfall to be overcome is four times every 10 years. Based on this probability exceedance level, the expected rainfall would be higher than the coffee evapotranspiration (for all conditions) in November, December, January, February and March (wet-season) (Figure 1a). In Uberlândia, 86% of the total annual rainfall (1,472 mm) occurred during the spring-summer or wet season (Ribeiro et al., 2013). From April to October the coffee evapotranspiration is higher than the historical monthly average rainfall (Figure 1a).

In irrigation projects the level of probability of exceedance considered suitable is 75% (an event that occurs three times every four years) (Bernardo et al., 2005). The probable rainfall with 75% of probability of exceedance (Figure 1e) is higher than coffee evapotranspiration only in December and January. In this context, it is important to stand out that the coffee vegetative growth and fructification periods occur from October to April-May (Matiello et al., 2010). In this period the coffee crop needs adequate soil moisture, which is guaranteed by rainfall, irrigation or management practices that contribute to soil water retention.

From the observations above, the use of historical monthly average rainfall in irrigation projects may be not suitable. Although studies such as this do not take into account the water retention by soil and other water cycle balance components, the observations in this work may play an important role in coffee irrigation management, indicating the contribution of rainfall. For example, the adequate designing of irrigation systems taking into account only the crop water needs can lead to an unnecessary use of water from rivers and lakes. Moreover, the use of historical average rainfall (without probabilistic studies) can lead to inadequate designing of the irrigation systems.

Figure 1 shows the monthly probable rainfall at seven probability levels of exceedance (Figure 1a-g). As can be seen, the increase in the accuracy level implies the reduction of the estimated value. For example, the probable rainfall with 95% of probability of exceedance (Figure 1g) is less than that with 40% of probability. As a consequence, with 95% probability of exceedance the probable rainfall does not reach the coffee evapotranspiration (for all conditions) for all months of the year.

Considering the 75% probability of exceedance level, in January the probable rainfall is 68, 31, 93, 56, 118 and 81 mm higher than coffee evapotranspiration for conditions I, II, III, IV, V and VI, respectively (Figure 1e). In February these values drop significantly. Only for conditions I, III, V and VI the probable rainfall exceeds the coffee evapotranspiration: 3, 28, 52 and 16 mm higher, respectively. In March the contribution of probable rainfall increase again. For conditions I, III, V and VI the minimum rainfall expected is 12, 36, 59 and 24 mm higher than coffee evapotranspiration, respectively. From April to October, where for the most part it is concentrated in the dry-season, the probable rainfall (75% of probability of exceedance) does not reach the coffee evapotranspiration in all conditions. In November, the minimum rainfall expected overcomes the coffee evapotranspiration in the conditions III,

Table 2. Descriptive statistics, β and ν parameters from Gamma model and Qui-Square Test (λ^2) for 30-day (monthly) rainfall data of Uberlândia (1975 to 2010), Minas Gerais state, Brazil.

Tabela 2. Estatística descritiva, parâmetros β e ν do modelo Gama e teste de Qui-Quadrado (λ^2) dos dados mensais de precipitação de Uberlândia (1975 a 2010), Minas Gerais, Brasil.

Month	Average rainfall (mm)	Standard Deviation (mm)	β	ν	λ^2*	λ^2**	P (%)
January	288	131	59.7	4.8	5.34	7.82	44
February	194	95	46.2	4.2	0.61	7.82	43
March	193	86	37.9	5.1	0.61	7.82	44
April	82	50	30.7	2.7	2.22	5.99	42
May	41	29	21.3	1.9	2.01	5.99	40
June	16	21	27.5	0.6	0.28	5.99	32
July	11	20	34.6	0.3	0.18	3.84	29
August	16	22	31.1	0.5	0.32	5.99	31
September	44	38	32.6	1.3	0.48	5.99	38
October	104	67	43.0	2.4	1.86	7.82	41
November	192	83	36.1	5.3	1.58	7.82	44
December	293	100	34.4	8.5	2.74	7.82	45

*and** calculated and standard λ^2, respectively. P: probability of occurrence of historical average rainfall for each period studied.

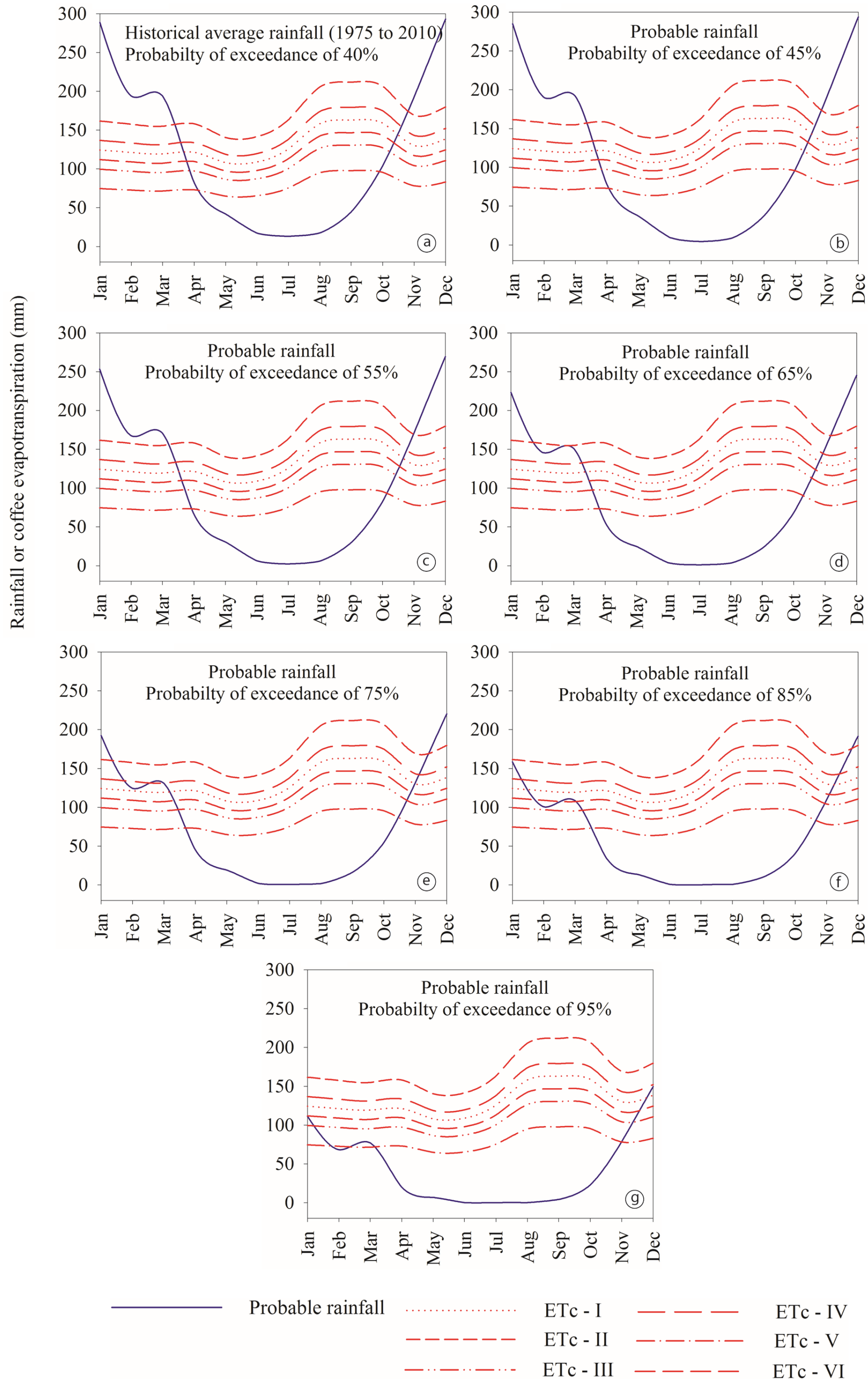

Figure 1. Monthly probable rainfall at different levels of probability of exceedance. (a) 40%; (b) 45%; (c) 55%; (d) 65%; (e) 75%; (f) 85%; (g) 95% and coffee evapotranspiration (ETc) for six conditions: ETc- I) > 3 years old, interrow> 3.0 m, row > 1.0 m, and Kc = 1.0; ETc - II) > 3 years old, interrow 1 to 2 m, row 0.5 to 1.0 m, and Kc = 1.3; ETc - III) 1 to 3 years old, interrow> 3.0 m, row > 1.0 m, and Kc = 0.8; ETc - IV) 1 to 3 years old, interrow 1 to 2 m, row 0.5 to 1.0 m, and Kc = 1.1; ETc - V) < 1 year old, interrow> 3.0 m, row > 1.0 m, and Kc = 0.6; ETc - VI) < 1 year old, interrow 1 to 2 m, row 0.5 to 1.0 m, and Kc = 0.9.

Figura 1. Precipitação provável mensal em diferentes níveis de probabilidade de excedência – (a) 40%; (b) 45%; (c) 55%;(d) 65%; (e) 75%; (f) 85%; (g) 95% e evapotranspiração do cafeeiro (ETc) para seis condições: ETc – I) Mais de três anos de idade, espaçamento entre linhas > 3,0 m, entre plantas > 1,0 m e Kc = 1,0; ETc - II) Mais de três anos de idade, espaçamento entre linhas de 1,0 a 2,0 m, entre plantas de 0,5 a 1,0 m e Kc = 1,3; ETc – III) Um a três anos de idade, espaçamento entre linhas > 3,0 m, entre plantas > 1,0 m e Kc = 0,8; ETc – IV) Um a três anos de idade, espaçamento entre linhas de 1,0 a 2,0 m, entre plantas de 0,5 a 1,0 m e Kc = 1,1; ETc – V) Menos de um ano de idade, espaçamento entre linhas > 3,0 m, entre plantas > 1,0 m e Kc = 0,6; ETc – VI) Menos de um ano de idade, espaçamento entre linhas de 1,0 a 2,0 m, entre plantas de 0,5 a 1,0 m e Kc = 0,9.

V and VI. In December, the contribution of probable rainfall is similar to January.

The occurrence and rainfall distribution and the crop evapotranspiration in a given region determine the irrigation needs. The Uberlândia city is located in a region considered a priority region for coffee irrigation in Brazil (Matiello et al., 2010). Coffee crops on areas with annual deficit of 100 mm do not respond to irrigation. On areas with deficit between 100 and 150 mm the coffee crop responds eventually. A deficit between 150 and 200 mm requires supplementary irrigation (Matiello et al., 2010).

The adoption of a permanent irrigation system throughout the year may contribute to higher productivity (Fernandes et al., 2000; Matiello et al., 2010; Serra et al., 2013). However, coffee phenology, coffee biochemistry, and some aspects related to coffee crop management should be strongly considered for the use of irrigation. For example, during the coffee harvest (July to September), the interruption of irrigation facilitates the fruit gathering operation and favors fruit quality. Moreover, the occurrence of water stress from July to September ensures the flowering uniformity (Nascimento et al., 2010). The water stress drives important biochemical reactions in coffee plants as shown by Brum et al. (2013). Souza et al. (2014) found that the interruption of irrigation contributed to higher uniformity and percentage of mature fruits of nine clones of Conilon "Vitória". In this context, the irrigation levels for coffee crop production and quality need to be more understood.

For coffee crop growing in Uberlândia, the maximum productivity was obtained when the irrigation levels was estimated at 60 and 70% of evaporation measured by the Pan method (Evangelista et al., 2013).Another study point out that the irrigations based on water-soil retention from 60 kPa and 100 kPa were adequate to coffee water needs in dense plantings (Serra et al., 2013).

The coffee irrigation evaluated from April to October in different times did not affect the coffee productivity and quality (Karasawa et al., 2002). However, an increase in the coffee productivity was observed for *Coffea Arabica* L. cv. Topázio MG-1190 in Lavras, Minas Gerais state, but the continuous irrigation retarded bean ripening (Rezende et al., 2006, 2010). The different irrigation managements did not significantly influence the total number of flowers, branches and percentage of flowers that resulted in fruits (Custódio et al., 2012).

Another aspect that should be taken in account is the incidence of pests and diseases in coffee irrigated areas. For example, the incidence of leaf-miner (*Leucoptera coffeella*) seems to be higher in non-irrigated plants compared to irrigated plants under the same conditions (Custódio et al., 2009). Similarly, in non-irrigated plants the incidence of Cercoscopora leaf spot was 30% greater than in irrigated plants (Paiva et al., 2013).

From this work an overview of the contribution of natural rainfall to coffee water requirements in Uberlândia is possible. By taking the probable rainfall into account, a better adequate designing of irrigation systems may be possible and also contribute to a rational use of water resources. Irrigation levels to be applied should be strongly studied for each condition, such as: soil type, coffee cultivar, coffee management, coffee phenology, and also to pay attention to the possibility of pest and disease incidence.

4 Conclusions

With 75% of probability of exceedance (suitable for irrigation purposes) the probable rainfall in Uberlândia overcomes the coffee evapotranspiration only in December and January, suggesting supplementary irrigation for vegetative growth and fructification periods (from October to April-May). During the entire dry-season the probable rainfall does not overcome the coffee evapotranspiration.

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