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OPTIMUM ECONOMIC IRRIGATION LEVELS OF CONILON COFFEE (*Coffea canephora*) IN THE NORTH FLUMINENSE REGION, BRAZIL

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Abstract: The economic evaluation of irrigation generally involves the quantification of productivity in response to the total water depth applied. The characterization of the crop response to the application of water has been widely known as the Water-Culture Production Function and in this sense, this work aimed to obtain the production function curve for Conilon coffee. (*Coffea canephora*), depending on the irrigation depths applied. The experiment was carried out in an existing crop field in the area belonging to the Universidade Estadual do Norte Fluminense Darcy Ribeiro in Campos dos Goytacazes, RJ, with a randomized block experimental design (DBC), composed by the water depth factor (0, 25, 50, 100 and 125% of ET_0) calculated using the FAO 56 Penman-Monteith method. Productivity data ($sc \cdot ha^{-1}$ and $kg \cdot ha^{-1}$) were obtained by weighing the fruits, harvested manually. The relationship between the dependent variables (productivity) and the independent variables (total water depth applied) was obtained by second degree polynomial regression analysis and, to determine the maximum productivity, in relation to the applied water depth, deriving the equation polynomial and equating the result to zero. From the obtained data, the production function equation was generated by second degree regression analysis to obtain the adjustment coefficients a, b and c. With the productivity data and the costs related to irrigation, the water depths were calculated to obtain the maximum physical productivity (W_{mpf}) and maximum economic yield (W_{mre}), considering grain productivity. It is concluded that the total blade of maximum economic efficiency was around 1600 to 1800 mm, while the blade of maximum physical productivity, between 1900 to 2000 mm, being economically viable the production in Norte Fluminense.

Keywords: Productivity, Irrigation Management, Water Deficit.

INTRODUCTION

Coffee stands out as one of the main products of Brazilian agricultural production, with Brazil being the world's largest producer and exporter of this commodity (MINISTRY OF AGRICULTURE, LIVESTOCK AND SUPPLY,2019). Considering only the Conilon species, Brazil becomes the second largest producer, with 15 million bags, behind only Vietnam, which produces approximately 31 million bags (Ministry of Agriculture, Livestock and Supply, 2020). According to data made available by the Companhia Nacional de Abastecimento-CONAB (CAFÉ, 2019), in Rio de Janeiro, the area planted with the coffee crop in production was 13,445 hectares, 3% higher than the 2017 crop. formation was 462 hectares.

Coffee growing in the North and Northwest Fluminense regions accounts for about 71% of all coffee production in the state of Rio de Janeiro, in addition, producers in these regions have become a reference in quality for the rest of the state. The good quality of the fruits is due to the introduction of new technologies, acquisition of individual and collective equipment, improvement of production processes in the field and post-harvest and support for opening new consumer markets (FERREIRA, 2016; KAWASAKI, 2018).

The cultivation of Conilon coffee is an option for diversification, given that the northern region of the state has areas with favorable characteristics for planting coffee, with an altitude of less than 500 meters, without pedological impediments, with an annual water deficit of less than 350 mm and temperature annual average of 22 to 26ºC (RODRIGUES et al., 2012).

According to these same authors, despite the climate and favorable conditions for cultivation, drought periods are recurrent in the region, in which plantations suffer from water stress due to the deficit generated.

In addition, good irrigation management can ensure better yields by reducing water consumption and guaranteeing this resource during most of the crop cycle. In this sense, Locatelli et al. (2014) highlight the inappropriate amount of water, whether due to lack or excess, as one of the main factors that limit production yield. To circumvent this problem or overcome this insufficiency, irrigation is used in order to supplement the crop's water needs during periods of drought.

Irrigation, therefore, aims to ensure productivity levels, guaranteeing stability in agricultural production, mitigating the risks of investments caused by the absence of rain. However, for its proper use, knowledge of the correct management of the system is necessary (PAES et al., 2012). According to Oliveira Neto et al., (2016), inevitably, the intense use of water for farming negatively affects water reserves. Knowledge of water availability and proper irrigation management allow for better management of water resources and an economic return on investments made.

One way of studying the effect of water application on crops is the use of production functions, which present the relationships between variations in crop yields as a function of variations in applied water volumes, with the independent variable "water" can be represented by the water depth applied during the crop cycle, evapotranspiration, soil water status and transpiration, but the applied water depth is the one of greatest interest to the irrigation user (SERRA et al., 2013).

In view of the above, this work aimed to obtain the production function curve for Conilon coffee (*Coffea canephora*), in the Norte Fluminense region as a function of the irrigation depths applied, as well as determining the depths that provide the maximum physical productivity (W_{mpf}) and the maximum average and general economic income. (W_{mre})

MATERIAL AND METHODS

LOCATION CHARACTERIZATION

The experiment was carried out in an existing crop field in the area belonging to the meteorological station of the Universidade Estadual do Norte Fluminense Darcy Ribeiro (Figure 1), located on the premises of the State Center for Research in Agroenergy and Waste Utilization (CEPEAA), at the Experimental of PESAGRO-RIO, in Campos dos Goytacazes, RJ in geographic coordinates 21° 24' 48" of South latitude and 41° 44' 48" of West longitude and 14 m of altitude, referring to the Datum WGS 1984.

According to the Köppen climate classification, the climate of the region is classified as Aw, that is, humid tropical climate, with rainy summers, dry winters and average air temperature in the coldest month above 18°C. The average air temperature is around 24.6°C, with an average annual rainfall of 981.6 mm, with summers being common in January and February (INMET, 2022).

The soil of the experimental area has a flat topography and was classified as Fluvic Neosol Tb dystrophic, according to the Brazilian soil classification system of EMBRAPA (1999).

EXPERIMENTAL DESIGN

The experimental design was randomized blocks (DBC), with four replications, composed by the water depth factor (0, 25, 50, 100 and 125% of the water depth). ET_0). The spacing used was 2.5 m between rows and 1.5 m between plants, totaling an area of 22.5 m2 per subplot and usable area of the subplot with 15 m2. Each subplot consisted of six plants, the two ends being considered borders.

The statistical model of the randomized block design can be represented by Equation 1:

$$Y_{ij} = m + T_i + B_j + \varepsilon_{ij} \tag{1}$$

Figure 1. Municipal boundary of Campos dos Goytacazes and the experimental field areas.

Source: Google (Upper left image) and José Carlos Mendonça (Other images).

FV	GL	SQ	QM	F
Block	j- 1	SQBlocks	QMBlocks	
Treatment	i - 1	SQTreatments	QMTreatment	QMTreatment/ QMResidue
Residue	(j - 1) (i - 1)	SQResidue	QMResidue	
Total	(ij - 1)	SQTotal		

j = Blocks; i = ETo Blade levels.

Table 1. Analysis of Variance Model for Randomized Block Design (DBC) with Respective Degrees of Freedom.

Where: Y_{ij} - observed value for the variable under study referring to the treatment "i" in the block j; m general average; T_i - effect of treatment i on the observed value: Y_{ij}; B_j - effect of block j on the observed value: Y_{ij}; $\boldsymbol{\varepsilon}_{ijl}$ - residual or random error associated with the observation: Y_{ij};

To calculate the estimated value of productivity, the values obtained by calculating the water depth applied in each treatment were substituted in the second degree polynomial equation generated.

The genotypes used were clones of the Vitória variety: clone 02 with an early cycle, and the pollinating clones in the P2 borders (medium cycle), aged 24 months, at the beginning of the evaluations. The application of correctives and chemical fertilizers was carried out based on the chemical analysis of the soil, according to Prezotti (2014) and, the cultural and phytosanitary treatments following the recommendations for the culture.

The sources of variation as well as the degrees of freedom for the split-plot model used in the work are described in Table 1.

MAINTENANCE OF THE EXPERIMENT AND CONDUCTION OF THE PLANTS

For the purposes of calculating the irrigation time required for the application according to the percentage of ETo, similar drippers with lower flow rates were considered among the models used, that is, 2.5 L h-1, for all treatments, the spacing and flow of drippers as presented in Equation 2, described by Bernardo, Soares and Mantovani (2006) and adapted by Lima Junior et al. (2011).

$$T_i = \frac{L_i \cdot S_p \cdot S_{lp}}{e \cdot q} \tag{2}$$

Where: Ti – irrigation time for each treatment, in hours; Li – water depth to be applied per treatment, in mm; Sp – spacing between plants, in m; Slp – spacing between rows of plants, in m; and - Number of emitters per plant; q – average emitter flow, in L·h-1.

Irrigation depths were determined as a function of reference evapotranspiration (ET0), calculated using the Penman-Monteith_FAO 56 method (Allen et al., 1998), with data collected at the meteorological station located next to the planting area.

Subsequently, water was applied based on the current Kc of the culture, in which the Kc varies between 0.7 and 0.8, from the ETo value being applied Kc equal to 0.7 in the period from July 2015 to January 2016, and subsequently, Kc equal to 0.8 was adopted until the end of this experiment.

PRODUCTION FUNCTION MODELING AND PRODUCTIVITY CALCULATION

Yield data (sc ha-1) were obtained through fruit harvest results in the 2016, 2017, 2018 and 2019 harvests, which took place in the dry season, between the months of May and August.

To estimate the total productivity in kg ha-1, Equation 3 was used.

$$Y = Ysc \cdot 60 \tag{3}$$

Where: Y - total crop yield, in kg·ha-1; Ysc – total productivity in bags per hectare;

The relationship between the dependent variables (productivity) and the independent variables (water depth applied) was obtained by second degree polynomial regression analysis, according to Equation 4 suggested by Frizzone and Andrade Junior (2005).

$$Y = a + b \cdot W + c \cdot W^2 \tag{4}$$

Where: Y – crop yield (kg·ha-1); W – total blade applied (mm); a, b, c – fit coefficients of the regression equation.

To determine the maximum productivity, in relation to the applied depth, Equation 4 was derived, equating the result to zero, as presented in Equations 5 and 6 (Vieira et al., 2014).

$$\frac{\sigma Y}{\sigma W} = b + 2 \cdot c \cdot W = 0 \tag{5}$$

$$W_{mpf} = -\frac{b}{2 \cdot c} \tag{6}$$

Where: Wmpf – blade of maximum physical productivity (mm);

According to the methodology described by Vieira et al. (2014) and Lyra et al. (2008), to determine the recommended irrigation depth for the Conilon coffee crop that produces the optimal point of economic yield (Wmre), the yield (profit) was initially estimated in relation to the applied depth, using the function represented by Equation 7 and then substituting Equation 6 into Equation 8 resulting in Equation 9.

$$L(w) = Py \cdot Y - (P_w \cdot W + C) + e_i \tag{7}$$

$$\frac{\sigma L}{\sigma W} = \frac{\sigma Y}{\sigma W} P_y - P_w \qquad (8)$$

$$W_{mre} = \frac{P_w - b \cdot P_y}{2 \cdot c \cdot P_y} \qquad (9)$$

Where: Wmre is the blade with maximum economic performance, in mm; a, b and c - adjustment coefficients of the regression equation; L - yield (R$·ha-1); Py - product price (R$·kg-1); Pw - price of irrigation water (R$·mm-1·ha-1); C - fixed costs of the irrigation system for the years under study (R$·ha-1).

The price of the product (Py) was obtained through the values collected from the sale and quotations from the Centro do Comércio do Café de Vitória-ES - CCCV, considering the average of the monthly prices practiced during the 2016 to 2019 harvests, which were, deducting the costs of administration, cargo insurance, sacks, transport, etc., of R$302.74, R$348.35, R$255.57 and R$233.86 for the 2015/2016, 2016/2017 harvests, 2017/2018 and 2018/2019, respectively, and Py values equivalent to 5.05 R$·kg-1, 5.81 R$·kg-1, 4.26 R$·kg-1, 3.90 R $·kg-1, in that same order. The general average for the period of the experiment was R$285.13 per bag and Py equivalent to 4.75 R$·kg-1.

In order to estimate the water price factor (Pw), the sum of the electric energy costs (EC) for operating the motor pump and the cost of the water tariff (TA) was considered.

Equation 10 was applied in the calculation of electricity costs (EC), according to Osti et al. (2017) and price per kWh charged, in the Rural Irrigating category – B2, according to the electricity supplier Enel Brasil.

$$CE = T_i \cdot F_m \cdot P_{kw} \qquad (10)$$

Where: CE – Electricity cost, in R$; Ti – Irrigation time, in hours; Fm – Engine power, in Kw; Pkw – Price charged per Kwh, in R$ per Kwh-1.

In the calculations of the water tariff (TA) the value of water abstraction per m^3 (Cw) and the water depth captured for each treatment (W) were considered, according to Equation 11.

$$TA = Cw \cdot W \qquad (11)$$

Where: Cw – Cost of water abstraction, in R$·m-^{3}; W – total blade applied, in mm.

From the sum of the calculated values for the EC and TA factors, the values of the Pw factors were obtained for each crop cycle, being 2.45 R$·mm-1·ha-1 for the 2015/16 cycle, 2.89 R $·mm-1·ha-1 for the 2016/17 cycle, 2.84 R$·mm-1·ha-1 for the 2017/18 cycle and 2.90 R$·mm-1·ha-1 in the cycle for the years 2018/19. The general average for the Pw factor value equivalent to R$ 2.82 R$ mm-1 ha-1.

The fixed irrigation costs (C), for the agricultural years under study, were obtained from the acquisition value of the equipment, divided by its useful life of 10 years (Cunha et al., 2012) and by the irrigated area of 1 (a) hectare, in addition to the cost of labor employed in irrigation.

The purchase values of the equipment were consulted at the store of agricultural products and instruments in the research region. Fixed costs of depreciation of system components (DC) and interest on invested capital (JC) were computed. Equation 12 was used to calculate equipment depreciation costs (Vieira al., 2014).

$$DC = \frac{[(VAC) - (0{,}15VAC)]}{VU} \qquad (12)$$

Where: DC – Depreciation of the system component, in R$; VAC – Acquisition value of the component, in R$; 0.15VAC – Residual scrap value, in R$; VU – Useful life, in years.

The residual value of 0.15 or 15% of the component's purchase value and the useful life of the system's instruments were obtained according to a review and data contained in the work carried out by Cunha et al. (2012).

The opportunity cost was calculated in order to represent the cost of financial market interest on invested capital, according to the method carried out by Vieira et al. (2014). The cost of interest on invested capital (JC) was calculated considering a rate of 4.5% p.a., applied to the acquisition value of the equipment, as shown in Equation 13.

$$JC = TAJ \cdot VAE \tag{13}$$

Where: JC – Interest on invested capital, in R$; TAJ – Annual interest rate, in %; VAE – Equipment acquisition value, R$;

With the yield data obtained in field conditions and the costs related to the irrigation of conilon coffee, the water depths to obtain the maximum physical productivity (Wmpf) and the maximum economic yield (Wmre) were calculated, considering the grain productivity.

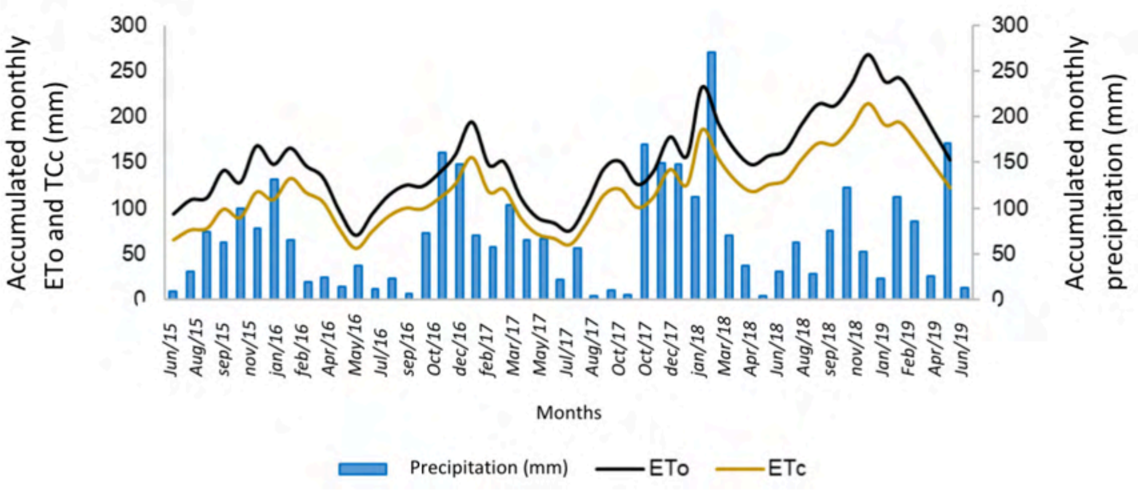
RESULTS AND DISCUSSION

MONTHLY CLIMATIC DATA FOR THE REGION DURING THE EXPERIMENTAL PERIOD

After collecting and tabulating the climatic data obtained using the meteorological station present in the area of the experiment, Graphs 1, 2 and 3 were plotted, in which the results obtained with the analysis of the averages of the local climatic variables, for the period of 2016 to 2019.

When analyzing Graph 1, a gradual increase in the general average of ETo can be seen, especially in the 2018/2019 cycle. Another important observation is the relationship between accumulated monthly rainfall and evapotranspiration. In this relationship, it can be seen that in most of the months evaluated, there was a tendency for the monthly accumulation of rain to accompany the increase in ETo, except for the 2018/2019 cycle.

This way, the cultivation of coffee for the region of Campos dos Goytacazes, in relation to the water deficit, can be classified with "Moderate Water Restriction", that is, Annual



Graph 1. Monthly accumulated values of Reference Evapotranspiration, Culture Evapotranspiration and Precipitation for the years 2016 to 2019.

Water Deficit between 200 to 400 mm and Summer Water Deficit between 40 to 80 mm, according to the classification presented by Ferrão et al. (2017).

For areas classified as Moderate Water Restriction, it is indicated that there are possibilities to commercially produce Conilon coffee, however, in a marginal way, that is, with lower production potential and higher climatic risks in relation to suitable areas. Therefore, it is necessary to use supplementary irrigation more frequently.

It is important to highlight that in the age and productive conditions in which the culture is, its real need for irrigation occurs through the evapotranspiration of the culture or ETc, therefore, the real need of the culture is around 70% to 80% of the ETo, that is, Kc varying between 0.7 and 0.8, with Kc equal to 0.7 being applied from July 2015 to January 2016, and then 0.8 until the end of this experiment, as methodology used by Venâncio et al. (2016).

In view of the general average data presented, it can be considered that the municipality of Campos dos Goytacazes has favorable environmental conditions for the cultivation of Conilon coffee, provided that irrigation is supplemented, since in the various data analyzed the conditions were in accordance with what is recommended for the culture as highlighted by Ferrão et al. (2017).

STATISTICAL RESULTS

From the productivity data collected and tabulated for each year, statistical analysis was performed and the results obtained are shown in Table 1.

By verifying the results detailed in Table 1, it can be inferred that there was a significant difference in the productivity results as a function of the applied water depths, both for the treatment variation source and for the different evaluated crops, which indicates that there is an influence both of the water volume applied, as well as the environmental conditions of each period.

Table 2 presents the results of the regression analysis of the four evaluated crops.

As it can be seen in Table 2, there was significance for both the values of b0 and b1 in the regression analysis of the general model, indicating that the regression coefficients for each crop are different depending on the applied depth and the condition of the production cycle.

PRODUCTIVITY AND OPTIMAL ECONOMIC LEVELS

Table 3 shows the general results obtained with the production averages of the four evaluated crops, with the average obtained and estimated for the region of Campos dos Goytacazes, RJ.

When detailing the results of Table 3, it can be seen that, in the average of the four harvests, the yields obtained for the treatments of 100 and 125% of ETo are statistically equivalent, however, in practice the difference in production is significant and equivalent to approximately 5 at 6 sc·ha-1, therefore, for an average price of 285.13 per bag, obtained from the average of the four harvests, the difference in reais is between R$1,425.65 and R$1,710.78 per hectare.

Another important fact is that, on average, for the conditions of this experiment, for treatments with water depths below 50% of ETo, the financial return obtained did not compensate for the investment made, except for the 2016/17 harvest in which the average price per bag of quoted coffee was high at R$425.28 sc-1.

Despite the low average productivity obtained in this experiment, in general, the production was above the national average, which varies between 35 sc·ha-1 and 41.35 sc·ha-1, according to INCAPER (2020) and

FV	GL	SQ	QM	Fc	Pr>Fc
Treatment	4	10838,99	2709,74	11,58	0,0000*
Harvest	3	20643,18	6881,06	29,40	0,0000*
Mistake	72	16849,98	234,02		
Total	79	48332,15			
CV			41,26%		

* Significant at 5% probability level.

Table 1. Analysis of Variance Table (ANOVA) for all production cycles of Conilon coffee.

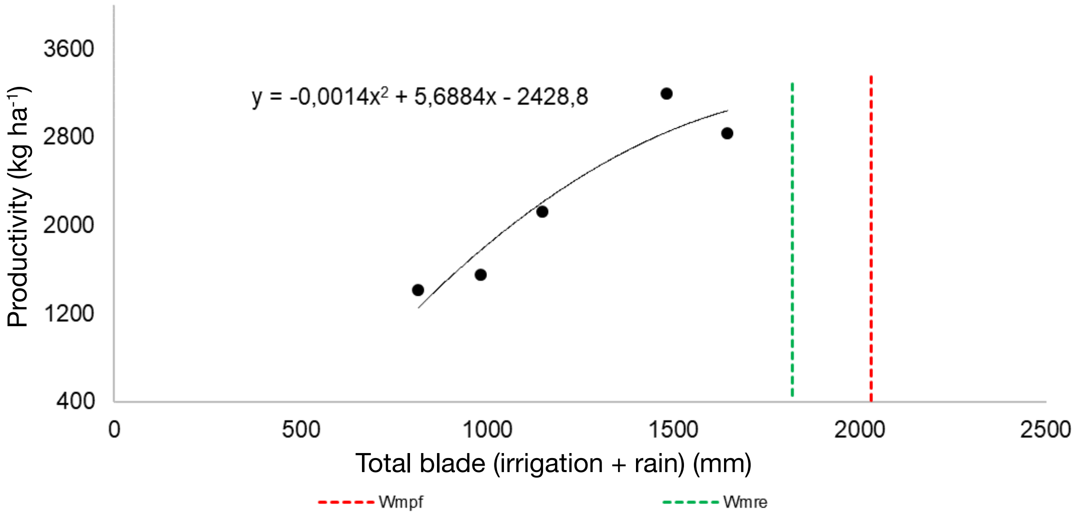
Parameter	Estimation	SE	T to H0: Par = 0	Pr> |t|
b_0	27,46	2,35	11,67	0,0000*
b_1	0,0016	0,00028	5,95	0,0000*
R^2		76,50%		

* Significant by t test at 5% probability level.

Table 2. Regression analysis table for the average of the four crops evaluated from 2015 to 2019.

Treatment	Total blade	Average productivity obtained		Estimated average productivity	
(%ET_0)	(mm)	$sc \cdot ha^{-1}$	$Kg \cdot ha^{-1}$	$sc \cdot ha^{-1}$	$Kg \cdot ha^{-1}$
0	815,98	23,56	1413,3	21,34	1280,65
25	982,84	25,89	1553,3	30,16	1809,62
50	1146,92	35,37	2121,9	37,56	2253,75
100	1482,45	53,30	3197,7	48,79	2927,25
125	1644,97	47,25	2835,1	52,34	3140,15

Table 3. Average overall yield obtained and estimated for all four crop cycles between 2015 and 2019 as a function of total water depth.



Graph 2. Production function for all four cultivation cycles between 2015 and 2019 in the Conilon coffee crop in the municipality of Campos dos Goytacazes. Wmpf – Maximum physical productivity blade; Wmre – Maximum economic performance blade.

MAPA (2020). It must be noted that there is a possibility of achieving greater production for the cultivation of Conilon coffee in the region of Campos dos Goytacazes, however, it requires investment and technologies on a larger scale.

Data from INCAPER (2020) suggest that some producers with higher technological level can reach yields above 100 sc·ha-1, however, this requires labor, fertilization and application of pesticides with high precision and proper management, in addition to the use of the correct irrigation depth.

Zanetti et al., (2015) in a study carried out with thirteen clones of the Vitória coffee tree, obtained an average productivity for clone V02 of 40.01; 43.32; 48.49; 46.94 and 48.16 sc·ha-1, for the depths of 40, 60, 80, 100 and 120% of ETo, respectively, presenting with these results values similar to those obtained in this experiment. While Bonomo et al. (2013), also for clone V02, obtained average yields between 71 and 122 sc·ha-1, with application of blades ranging from 25 to 125% of ETo.

The general average curve of the four harvests that relates the applied depth and the productivity obtained for each one of the treatments are presented in Graph 2.

By the graphical analysis it can be verified that, for the conditions applied in this experiment, the total depth of maximum economic efficiency was around 1600 to 1800 mm, while the depth of maximum physical productivity varied between 1900 to 2000 mm. It is important to note that the results obtained in the 2018/2019 cycle were different from the others, which raised the general average of Wmre and Wmpf.

Lima Junior et al., (2011) point out that when the production function presents very approximate values of Wmpf and Wmre, this fact may be related, mainly, to the type of irrigation system being used, because as it is a question of a localized irrigation system, which is characterized by working with high application efficiency, reducing costs, which will possibly provide reduced values for the price of the water factor.

This result also indicates that irrigation must be carried out in order to guarantee the maximum vegetative and productive development of the crop, under optimal conditions of soil moisture.

In contrast, it can be seen that when marketing costs are high or the amount paid for a bag of coffee is low, the distance between the Wmpf and Wmre points is greater.

When comparing the blade with maximum economic yield and that of maximum physical productivity, several authors observed very similar values for these two parameters, in different cultures (Bilibio et al., 2010; Lima Júnior et al., 2010; Santana et al., 2010; Santana et al. al., 2009; Oliveira et al., 2011a; Pelegrini et al., 2020).

According to Oliveira et al. (2016) this fact is probably due to the high economic value of these crops, which increases the profits with the application of water depths to maintain soil moisture close to field capacity.

Results achieved by Silva et al. (2007) agree with those obtained in this experiment, since these authors evaluated that a replacement of 161.1% of the evaporation resulted in a productivity of 112.1 sc·ha-1.

Although the curve presented in Graph 2 indicates that an increase in irrigation by 63%, approximately 900 mm, would increase production by 24 sc·ha-1, it is believed that this factor alone would not be able to meet the physiological demands of the plants, it is also necessary to increase the application of fertilizers and correctives, as reported by several authors (Bravin et al., 2019; Burak et al., 2016; Busato et al., 2015).

CONCLUSION

In the average of the four harvests, under the conditions of the present study, the depth of maximum physical productivity was 2031.57 mm and the depth of maximum economic yield was 1819.49 mm. Therefore, based on the most recent climatological normal for the Campos dos Goytacazes region, an irrigation supplementation with 1049.97 mm and 837.89 mm must be performed to reach these two optimal levels, respectively.

Regarding the costs of marketing Conilon coffee, further studies are needed to estimate these values, since the values practiced by cooperatives and associations differ from data found in the literature.

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