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Water balance: infiltration, evaporation and evapotranspiration

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VARIABILITY OF WATER BALANCE COMPONENTS IN A COFFEE CROP GROWN IN BRAZIL[1]

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ABSTRACT

The establishment of field water balances is difficult and costly, the variability of its components being the major problem to obtain reliable results. This component variability is here presented for a coffee crop grown in the Southern Hemisphere, on a tropical soil with 10% slope. It is concluded that rainfall has to the measured with an appropriate number of replicates, that irrigation can introduce great variability into calculations, that evapotranspiration calculated from the water balance equation has too high coefficients of variation, that the soil water storage component is the major contributor in error propagation calculations, and that the run-off could be satisfactorily controlled on the 10% slope through crop management practices.

Keywords: water balances; component variability; rainfall; evapotranspiration; soil water storage

VARIABILIDADE DOS COMPONENTES DO BALANÇO HÍDRICO DE UMA CULTURA DE CAFÉ NO BRAZIL

RESUMO

O estabelecimento de balanços hídricos no campo é difícil e dispendioso, sendo a variabilidade de seus componentes o maior problema para se obter resultados confiáveis. Esta variabilidade dos componentes é aqui apresentada para uma cultura de café desenvolvida no hemisfério sul, em um solo tropical com 10% de declividade. É concluído que a chuva deve ser medida com um número apropriado de repetições, que a irrigação pode introduzir grande variabilidade dos cálculos, que a evapotranspiração calculada a partir da equação do balanço hídrico tem coeficientes de variação muito altos, que o componente armazenamento de água no solo é o que mais contribui na propagação dos erros e que a enxurrada pôde ser satisfatoriamente controlada nesse declive de 10% por meio de práticas de manejo.

Palavras-chaves: balanço hídrico; variabilidade dos componentes; chuva; evapotranspiração; armazenamento de água

INTRODUCTION

Water balances are of extreme importance to follow water dynamics in agricultural and natural ecosystems. They indicate, in space and time, the conditions under which plants grow and develop, being useful in the interpretation of plant behavior during periods that differ from the normal climatic condition of the place in question, such as periods of water excess or deficit. These aspects are of great importance for crop management and the understanding of the behavior of natural ecosystems. A non-response of a crop to a fertilizer or the disappearance of a given natural species, can be partially explained in light of consistent water balances.

The coffee crop is among the most important crops in Brazil, being cultivated over an area of almost 3 million ha, with a production of 34 million bags of dry beans (60 Kg each) per year (FNP, 2002). Among the several factors that affect the productivity of this crop, of extreme importance are the water relations in the soil-plant-atmosphere system and the availability of nutrients, mainly nitrogen. The establishment of water balances is an excellent tool to better understand these water relations with respect to the growth and development of the crop, and to quantify important nitrogen losses by leaching, volatilization and run-off.

The establishment of field water balances is time consuming and costly due to the required equipment. For this reason they are seldomly replicated in order to obtain significant average values. Since the water balance is an addition of several components, each of them having its own space and time variability, error propagation can lead to inconsistent results. Villagra et al. (1995) discuss this variability problem in a study comprising 25 balance replicates, their main problem being the estimation of soil water fluxes below the rootzone.

With the objective of contributing to a better understanding of water relations of the coffee crop, we present the variability of the water balance components, using five replicates distributed within a 0.2ha coffee crop.

MATERIAL AND METHODS

1. Experimental Field

The experiment was carried out in Piracicaba, SP, Brazil, (22^{o0}42`S, $47^{o}$38`W, 580m above sea level) on a soil classified as Rhodic Kandiudalf, locally called “Nitossolo Vermelho Eutroférrico”, A moderate and clayey texture. The climate is Cwa, according to Köppen’s classification, mesothermic with a dry winter, in which the average temperature during the coldest month is below 18^{o}C and during the hottest month, is over 22^{o}C. The annual average temperatures, rainfall, and relative humidity are 21.1^{o}C, 1,257 mm, and 74%, respectively. The dry season is between April and September; July is the driest month along the year. The wettest period is between January and February. The amount of rainfall during the driest month is not over 30 mm (Villa Nova, 1989).

Coffee plants (*Coffea arabica* L.), cultivar "Catuaí Vermelho" (IAC-44) were planted in line along contour-lines in May 2001. The spacing in rows was 1.75 m and 0.75 m between plants. The total coffee area of 0.2 ha was divided into 15 plots with nearly 120 plants each. This arrangement was used in order to distribute randomly three treatments of a parallel Nitrogen Balance study, with five replicates.

The experimental evaluations started on September 1, 2003 at 8.00am. The following dates received the code DAB (days after beginning, since the crop is perenial) followed by the number of days. It is important to mention that a field day starts at 8.00am and finishes in the following day at 8:00am.

Only the five replicates of the treatment with highest rate of N-fertilizer (T_2) were used in order to establish the water balances, made in sub-plots with nine plants covering an area of 11.8125 m^2, on a 10 ± 2 % slope. These plots were fenced to perform the nitrogen balance, fertilizing the area with enriched ammonium sulphate. The experimental area is located under the edge of a central-pivot irrigation system which, therefore, did not permit very regular applications of water depths. An automatic meteorological station was installed nearby (about 200 m).

The experimental design, used in the parallel N study consisted of randomized blocks with three treatments of N, T_0, T_1 (1/2 rate), and T_2 (1 rate), receiving 280 $kg.ha^{-1}$ of N split into 4 applications (DAB-0, DAB-63, DAB-105, and DAB-151), with a regular P and K fertilization.

2. Water Balance

Water balances started on September 1, 2003 (DAB-0) and continued to be established for 14 day periods $(\Delta t = t_{i+14} - t_i)$, continually, until August 30, 2004 (DAB-364), completing one year. The classical water balance equation representing the mass conservation law was used, considering water fluxes entering and leaving a soil volume element, integrated over time for 14 day periods, $\Delta t = t_{i+14} - t_i$:

$$\int_{t_i}^{t_{i+14}} p dt + \int_{t_i}^{t_{i+14}} i dt - \int_{t_i}^{t_{i+14}} e dt - \int_{t_i}^{t_{i+14}} r dt \pm \int_{t_i}^{t_{i+14}} q_L dt + S_{i+14} - S_i = 0 \qquad (1)$$

which by solving the integrals results in:

$$P + I - ER - RO - Q_L + \Delta S = 0 \quad (2)$$

where P=rainfall; I=irrigation; ER=actual evapotranspiration; $\Delta S = S_{i+14} - S_i$ = soil water storage changes in the soil 0–L layer; RO = runoff; and Q_L = deep drainage at the lower boundary of the soil volume at the depth z = L, all expressed in mm.

Rainfall (P) was measured daily and integrated over Δt at each replicate, using traditional rain-gauges ("Ville de Paris") with 0.04047 m^2 collecting areas, installed in the sub-plots 1.2 m above soil surface. Due to the presence of obstacles in the neighborhood of the experimental area, such as, a silo, a warehouse, orchards, and tall trees, the rainfall was measured in each T_2 plot using 5 rain-gauges, opening the possibility of obtaining average values ($\overline{P}$) with standard deviations [s(P)] and coefficients of variation (CV).

Irrigation for coffee in this region of Brazil is supplementary, applied only during periods of severe drought, in our case through the central-pivot system. As mentioned above, the coffee crop plots were at the edge of this irrigation system, which increased the variability of water application. This variable was also measured by the 5 rain-gauges installed for rainfall measurement.

The criteria of amount and time of irrigation were mostly based on physiological aspects of the coffee plant that requires a cold and dry winter to blossom, which starts after the first significant rain. After blossoming, an excessive lack of water may cause flower loss. Therefore, the decision to irrigate was taken by visual observation of the water deficit, trying to apply 30 mm of water depth that approximately would wet a 0.6 m soil layer.

The actual crop evapotranspiration (ER) was estimated by difference from all other components, using equation (2). In wet periods, with a drainage (Q_L) likely to happen and considering it as zero in equation (02), ER, now named ER', was overestimated because it includes Q_L. Thus, in periods in which ER was larger than the potential evapotranspiration (ET), ER was considered equal to ET and the difference $ER–ET=Q_L$. The potential evapotranspiration was estimated from the reference evapotranspiration (ET_0) corrected by the crop coefficient (K_C). ET_0 was calculated using Penman-Monteith equation (Pereira et al., 1997), with meteorological data collected at the automatic weather-station installed near the experimental area. K_C was calculated by dividing ER by ET_0 along the periods in which the plants were not under stress, when the soil water storage was relatively high and without drainage. The above referred K_C was the average value obtained for these periods. Since ER was calculated from the balance equation (2) its variability was estimated through error propagation:

$$s^2(ER') = s^2(P) + s^2(I) + s^2(RO) + s^2(S_{i+14}) + s^2(S_i) \qquad (3)$$

and $s(Q_L)$ was taken equal to $s(ER')$ since it was calculated by the difference ER'-ET, considering ET an absolute value.

The soil layer 0-1m (L=1m) was chosen to calculate soil water storages $S(t_i)$ since at this stage of the crop this soil layer contains more than 95% of the root system. $S(t_i)$ was estimated from soil water content measurements ($\theta, m^3.m^{-3}$) obtained by a neutron probe, using three access tubes installed down to the depth of 1.2 m in each plot, making up a total of 15 tubes. The calibration of this probe, model CPN 503 DR, was made in an area close to the experimental field. The moisture contents were measured at 0.20, 0.40, 0.60, 0.80, and 1.00 m at the selected dates t_i, during the experimental period, which started at t_i (DAI-0) and continued up to t_{i+14}, Δt = 14 days. $S(t_i)$ was calculated using the trapezoidal rule:

$$S(t_i) = \int_0^L \theta(t_i)dz = [\bar{\theta}(t_i)].L \qquad (4)$$

where $\bar{\theta}(t_i)$ is the average θ at time t_i and the soil depth L, in this case taken as 1,000 mm in order to obtain S expressed in mm.

For measuring the runoff, each experimental plot was framed by metal dicks, and the water was collected by gravity in 60L tanks placed downslope.

RESULTS AND DISCUSSION

1. Rainfall (P)

The accumulated values of P for each water balance period (14 days) are presented on the Table 1. Despite rain-gauges being relatively near to each other (15 to 100 m apart), there was a significant variability among the readings performed over the five replicates. Generally speaking, the CV values were low (2 - 4%), but some of them presented higher values, mainly those from water balances 2, 16, and 22, with CVs over 10%. For balances 2 and 22 this can be explained through the low amounts of rainfall, and balance 16 has an unexplained out-layer of 78.6mm in an average of 65.2mm.

This data variability justifies the need for measuring P in replicates as made in this study. Reichardt et al (1995) discuss the problem of rainfall variability using the city of Piracicaba as an example. They also demonstrated that spatial variability has to be taken into consideration and that rainfall has to be measured as close as possible to the experimental area as it was made in this study, mainly for short time periods like 14 days.

During the whole agricultural year, balances 1 to 26, the total amount of rainfall was a little higher than 1,275 mm, the historic rainfall average for the region, revealing that the year under study was within the normal rainfall parameters.

Insert Table 1

2. Irrigation (I)

As mentioned before, the irrigation was supplementary and applied only to avoid water deficits which could irreversibly damage the crop. In the Piracicaba region, irrigation practices are not part of the coffee crop management.

The dry period during the winter extends from July to September in Piracicaba and, during this period, the coffee plants are subject to water deficit and, as a physiological response, a high proportion of the leaves drop. At the end of this period, rain triggers blossoming and continued water deficit can affect flower setting, making irrigation necessary. At the beginning of the experiment (DAI=0) the coffee plants were under a strong water deficit and for this reason, even with a small rainfall (4.1 mm), irrigation was applied, as shown in Table 2. The variability of this irrigation was even greater than that of the rainfall (CV=35.1%) due to the factors previously mentioned: edge of the central-pivot, wind drift, obstacles, etc. According to the chosen speed for the central-pivot, the amount applied should have been 30 mm, which is very different from the measured values shown in Table 2.

During the following winter (2004), another additional irrigation was needed during water balance 26 for the same reasons mentioned before. The variability, this time, presented a CV of 41.7%.

Despite the difficulties occurred during irrigation, the total amount of water applied artificially was very small in relation to the total amount of rainfall and the irrigation variability affected only the estimates of two water balances (1 and 26). The irrigations were necessary for relieving the coffee crop from the water stress that occurred during those periods.

Insert Table 2

3. Actual Evapotranspiration (ER)

Table 3 presents ER' data together with s(ER'), CV, ET_0, K_C, ET_C, the evapotranspiration corrected by drainage ER, and Q_L. Water balances 5 to 22 were chosen to estimate Kc by means of the relation ER/ET_0. During these balances soil water storage S_L was high enough to assume that plants had no restriction to soil water and that differences between ER and ET_0 are due to plant architecture and to percent of crop cover. Exception was made to balances 11, 13 and 20, during which drainage Q_L occurred. The variability of K_C is large, ranging from 0.6 and 1.7, with an average of 1.1, standard deviation 0.3, and CV=31.2%. In order to complete the K_C column on Table 3, the average Kc was considered for the water balances under water deficit and with drainage.

The highest ER value was the one obtained in balance 12, of 6.8 mm.day^{-1}, which is a coherent value for February in Piracicaba. The lowest values occurred on the balances 2, 23, and 25, with 0.9, 0.5, and 0.8 mm.day^{-1}, respectively. During these periods, coffee plants were under water deficit and, consequently, losing their leaves.

Table 4 presents the calculation of the standard deviation $s(ER')$ of the actual evapotranspiration, calculated through error propagation since this component was obtained as an unknown in equation (2). From this table it can be seen that the greatest contribution to $s(ER')$ comes from $S(t_i)$ measurements. As a result $s(ER')$ is very large in relation to its average ER', indicated by the high CVs presented in Table 3. They varied from 27.4% to 469.1%, showing a great uncertainity in measuring actual evapotranspiration from water balances. Most of the high CVs correspond to wet periods, when ER was close to ETc, periods during which aerodynamic models like the combined methods of Penman, Slatyer & McIlroy, and Penman-Monteith (Pereira et al, 1997), give much better estimatives. We, therefore, do not recommend the estimation of ER through water balances, a fact that does not depreciate water balances, since they are useful in many water management practices, reflecting in space and time, the water availability to the crop.

Insert Table 3

Insert Table 4

4. Soil water storage $S_L(t_i)$

Table 5 shows the variability of the soil water storage (S_L) calculated through the trapezoidal rule (equation 4) from soil water content (θ) data collected by the neutron probe. The CVs are relatively low and very consistant. Since three access tubes were placed in each plot, each average $\overline{S_L}$ is the result of 15 measurements, that should be a good estimative of the soil water situation at the moment t_i. Neutron probes have the advantage over the classical methodologies of allowing measurements along time at exactly the same positions. This explains the homogeneity of the CVs. The variability of the data shown in Table 5 is a picture of the soil water variability of the experimental field. Using the conventional methods, such as auger sampling, it would not be possible to measure θ always at the same positions. This fact would increase a lot the variability of the data and would require a much larger experimental area due to the destructive samplings.

Through an analysis of Table 5 one can see that the lowest value S_{Lmin} is for balance 1 (245.2mm) corresponding to a severe water stress condition, but still high enough to maintain the crop growing. The maximum S_{Lmax} refers to balance 12 (369.9 mm), corresponding to the wettest condition, in which there was even drainage. With these extreme values the available water capacity of this soil profile (S_{Lmax}-S_{Lmin}) can be evaluated. This difference is 125 mm, which represents the maximum possible variation of S_L in this crop down to the depth of 1 m, for this particular soil.

Insert Table 5

5. Runoff (RO)

The runoff was very small in relation to the other components (1.7% in relation to rainfall) and presented a great variability, not appearing in all plots and in an unconsistant way. This means that the coffee crop planted on a 10% slope along contour-lines was adequate for runoff control and, consequently, erosion.

Insert Table 6

The high CVs presented in table 6 have to be analysed carefully. The presence of many null values may indicate that this variable probably does not follow the normal distribution and with very low mean values, CVs tend to increase by definition, even when the variable is correctly measured. Anyway, the absolute values of RO were very small and affected very little the establishment of water balances.

6. Water balances

Table 7 shows all water balance components in a joint way.

Insert Table 7

The historic average of annual rainfall in the city of Piracicaba is 1,275 mm, which shows that this year (Sept.2003/Sept.2004) was slightly more rainy than normal. The irrigation in this region is not necessary for the majority of the perennial crops, such as coffee. The amount of irrigation water applied (71.6 mm) was only for preventing blooming to be damaged during water stress periods. Considering water inputs (P+I), it is verified that RO represents only 0.4% of the balance, which means that this component was insignificant under the experimental conditions evaluated in this study. Figure 1 shows a tendency of increasing RO as a function of increasing P. This fact is expected, but is very hard to be forecasted once RO depends more on rain intensity than on the total amount of water. It is also influenced by $S_L(t_i)$, which when low favours water infiltration.

The drainage below the depth z =1.0 m was 12.5% of the balance, which can be more significant in wetter years. In terms of N leaching, a reflex of drainage, it can be concluded that the coffee fertilization and its splitting were adequate in relation to the water balance components.

As the annual variation of ΔS should theoretically, be small over long periods such as a year (-5.5 mm in our case), the remaining of the water balance is ER, representing 82.5%. Under an ideal situation, in which RO and Q_L are null, ER would represent 100% of (P+I), that is, ER = (P+I). Such condition almost happened over the studied year.

Insert Figure 1

Insert Figure 2

Figure 2 shows the distribution of rainfall and of evapotranspiration along the year (Sept.2003/Sept.2004). In general, the rainfall was well distributed, except for the unsual high rainfall rate during June and July (balances 20 to 24), which are generally drier months in the region. This exception guaranteed a good development of the crop. The end of the dry seasons, represented by balances 1 and 2; 25 and 26, demanded irrigation. The highest rainfall occurred during the balances 11 and 13, and, as a consequence, the drainage (Q_L) was 12.5% of (P+I).

The actual evapotranspiration got closer to the maximum almost along the whole year, except for the dry periods (balances 1, 2, 4, 23, 25, and 26). During these periods, the coffee plants lost part of their leaves because the soil hydraulic conductivity was too low, defining a water flux to the plant root system that does not attend the atmospheric demand.

CONCLUDING REMARKS

1) Rainfall is generally measured only at one point and, in many cases one takes the value of the nearest meteorological station. We verified that in experimental areas having obstacles nearby which affect the dynamics of the wind and, consequently, of the rainfall, the measurement of the rainfall should be made with an adequate number of replicates. In our case, an area of 0.2 ha, with trees, silo, and warehouse located within 100 m of distance, 5 rain-gauges apart from each other by 15 to 100 m, presented CVs up to 17.8%;

2) Irrigation can introduce great variability in water balance calculations when not well controlled, due to operational problems and wind drift;

3) The atmospheric demand of the coffee crop, expressed by its actual evapotranspiration, was 1141.7 mm per year. It was not affected by the parameters that characterize the stadia of growth and development of the crop. Its estimation through water balance calculations is not recommended due to error propagation. Alternative aerodynamic methods are better choices;

4) The soil in question presents a maximum capacity of soil water storage of the order of 125 mm, which represents a backup of water for 25 days, without considering the restrictions on water flux to the roots in drier periods and considering an average demand of 5 mm/day. In this year the rainfall was near to the long term average, and was enough to meet the atmospheric demand of the crop, with restrictions in the period of dry and cold winter, favorable for blossoming. Soils with smaller storage capacity are likely to cause water supply problems and also permit larger values of internal drainage and, consequently, leaching. Soil water storage, although measured carefully, was the component that introduced most variability and error propagation in water balances;

5) The planting of coffee in areas with slopes has to be made in such a way to provide good water infiltration, minimizing runoff losses and the erosion process. Planting made in furrows along contour-lines, reduced considerably the runoff and the erosion was nil. In our case, with an average slope of 10%, the value runoff was very small, of the order from 1.7% in total of the rainfall. As expected, a positive relation between the runoff and the rainfall was observed.

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Table 1: Average rainfall (P), standard deviations [s(P)], and coefficients of variation (CV) of each period.

Balance	Period	DAB	Rainfall (P)							
			1	2	3	4	5	$\overline{P}$	s(P)	CV
1	01/09 to 15/09	0_14	4.0	4.2	4.3	4.2	4.0	4.1	0.1	3.2
2	15/09 to 29/09	14_28	5.8	5.8	6.4	4.8	6.2	5.8	0.6	10.6
3	29/09 to 13/10	28_42	79.0	75.4	80.6	78.0	75.9	77.8	2.2	2.8
4	13/10 to 27/10	42_56	18.2	18.1	18.2	17.6	17.5	17.9	0.3	1.9
5	27/10 to 10/11	56_70	25.4	24.9	26.3	24.5	25.5	25.3	0.7	2.7
6	10/11 to 24/11	70_84	75.7	74.2	78.7	74.2	72.5	75.1	2.3	3.1
7	24/11 to 08/12	84_98	93.9	88.9	91.8	87.4	86.7	89.7	3.0	3.4
8	08/12 to 22/12	98_112	51.0	49.8	49.3	48.5	48.0	49.3	1.2	2.4
9	22/12 to 05/01	112_126	89.2	86.5	85.1	84.4	82.8	85.6	2.4	2.8
10	05/01 to 19/01	126_140	52.4	51.1	50.5	49.6	49.3	50.6	1.2	2.5
11	19/01 to 02/02	140_154	173.7	168.4	165.7	166.7	164.2	167.7	3.7	2.2
12	02/02 to 16/02	154_168	73.9	71.4	69.1	67.9	66.9	69.8	2.8	4.0
13	16/02 to 01/03	168_182	156.6	156.3	153.7	149.2	148.8	152.9	3.7	2.5
14	01/03 to 15/03	182_196	75.9	74.8	72.2	71.4	71.2	73.1	2.1	2.9
15	15/03 to 29/03	196_210	14.4	14.4	14.0	13.8	13.2	14.0	0.5	3.6
16	29/03 to 12/04	210_224	59.4	78.6	62.2	65.0	61.0	65.2	7.7	11.9
17	12/04 to 26/04	224_238	54.7	53.6	51.8	50.9	50.7	52.3	1.7	3.3
18	26/04 to 10/05	238_252	23.9	24.1	22.9	22.3	22.7	23.2	0.8	3.4
19	10/05 to 24/05	252_266	27.4	27.2	25.1	23.9	24.1	25.5	1.7	6.5
20	24/05 to 07/06	266_280	105.5	104.5	101.1	98.5	97.7	101.5	3.5	3.4
21	07/06 to 21/06	280_294	7.6	8.0	7.1	6.7	6.5	7.2	0.6	8.7
22	21/06 to 05/07	294_308	2.4	2.0	1.8	1.6	1.6	1.9	0.3	17.8
23	05/07 to 19/07	308_322	33.2	33.1	32.5	32.2	32.3	32.7	0.5	1.4
24	19/07 to 02/08	322_336	46.8	45.4	43.9	43.6	43.1	44.6	1.5	3.4
25	02/08 to 16/08	336_350	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	16/08 to 30/08	350_364	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	01/09 to 30/08	0-364	1350.0	1340.7	1314.3	1286.9	1272.4	1312.9	33.4	2.5

Table 2: Average irrigation $(\bar{I})$, standard deviations s(I), and coefficients of variation (CV) for two periods.

Balance	**Period**	**DAB**	**Irrigation**		
			$\bar{I}$	**s(I)**	**CV**
1	01/09 to 15/09	0_14	34.2	12.0	35.1
26	16/08 to 30/08	350_364	37.5	15.6	41.7

Table 3: Average actual evapotranspiration (ER'), its standard deviation [s(ER') calculated through equation 03], reference evapotranspiration (ET_0), crop coefficient (K_C), potential evapotranspiration (ET_C), ER and the drainage below root zone (Q_L) for each period.

Balance	**DAB**	$\overline{ER'}$ **(mm)**	**s(ER')**	**CV**	$\overline{ET_0}$ **(mm)**	K_C	$\overline{ET_C}$ **(mm)**	**ER=ER'-Q_L (mm)**	$\overline{Q_L}$ **(mm)**
1	0_14	-26.1	33,65	129,0	-45.9	1.1	-50.1	-26.1	0,0
2	14_28	-11.9	29,92	250,9	-56.0	1.1	-61.2	-11.9	0,0
3	28_42	-50.9	31,25	61,3	-53.9	1.1	-58.9	-50.9	0,0
4	42_56	-24.8	32,00	129,1	-65.4	1.1	-71.5	-24.8	0,0
5	56_70	-33.1	33,19	100,3	-47.5	0.7	-33.1	-33.1	0,0
6	70_84	-62.3	32,90	52,8	-60.3	1.0	-62.3	-62.3	0,0
7	84_98	-72.0	30,74	42,7	-50.5	1.4	-72.0	-72.0	0,0
8	98_112	-57.5	31,10	54,1	-62.4	0.9	-57.5	-57.5	0,0
9	112_126	-68.1	33,87	49,7	-57.5	1.2	-68.1	-68.1	0,0
10	126_140	-52.2	33,28	63,7	-63.2	0.8	-52.2	-52.2	0,0
11	140_154	-97.4	33,95	34,9	-39.3	1.1	-42.9	-42.9	-54,4
12	154_168	-95.5	34,66	36,3	-62.0	1.5	-95.5	-95.5	0,0
13	168_182	-130.6	35,80	27,4	-46.8	1.1	-51.2	-51.2	-79,4
14	182_196	-89.3	36,28	40,6	-52.3	1.7	-89.3	-89.3	0,0
15	196_210	-62.4	33,95	54,4	-55.3	1.1	-62.4	-62.4	0,0
16	210_224	-64.2	33,61	52,4	-47.7	1.3	-64.2	-64.2	0,0
17	224_238	-51.7	32,31	62,5	-36.1	1.4	-51.7	-51.7	0,0
18	238_252	-29.6	33,03	111,6	-35.6	0.8	-29.6	-29.6	0,0
19	252_266	-25.6	32,92	128,8	-24.4	1.0	-25.6	-25.6	0,0
20	266_280	-46.8	30,75	65,6	-23.4	1.1	-25.6	-25.6	-21,3
21	280_294	-19.6	31,51	160,5	-29.9	0.7	-19.6	-19.6	0,0
22	294_308	-21.9	33,59	153,2	-35.4	0.6	-21.9	-21.9	0,0
23	308_322	-6.6	31,13	469,1	-27.7	1.1	-30.2	-6.6	0,0
24	322_336	-57.5	30,00	52,2	-35.7	1.1	-39.0	-39.0	-18,5
25	336_350	-11.4	30,48	266,5	-45.1	1.1	-49.3	-11.4	0,0
26	350_364	-46.1	30,26	65,7	-46.7	1.1	-51.0	-46.1	0,0
1_26	0_364	-1315,3	-	-	-1206,0	1.1	-1318,3	-1141,7	-173,6

Table 4: Estimation of the standard deviation s(ER') of the actual evapotranspiration ER', using error propagation (equation 03).

Balance	DAB	s(P)	s(I)	$s(S_F)$	$s(S_I)$	s(RO)	s(ER')
1	0_14	0,1	12,0	20,7	23,7	0,0	33,6
2	14_28	0,6	0,0	21,6	20,7	0,0	29,9
3	28_42	2,2	0,0	22,5	21,6	0,3	31,2
4	42_56	0,3	0,0	22,8	22,5	0,0	32,0
5	56_70	0,7	0,0	24,1	22,8	0,0	33,2
6	70_84	2,3	0,0	22,3	24,1	0,4	32,9
7	84_98	3,0	0,0	21,0	22,3	0,3	30,7
8	98_112	1,2	0,0	22,9	21,0	0,0	31,1
9	112_126	2,4	0,0	24,8	22,9	0,8	33,9
10	126_140	1,2	0,0	22,1	24,8	0,1	33,3
11	140_154	3,7	0,0	25,5	22,1	0,7	33,9
12	154_168	2,8	0,0	23,3	25,5	0,4	34,7
13	168_182	3,7	0,0	26,9	23,3	1,1	35,8
14	182_196	2,1	0,0	24,3	26,9	0,7	36,3
15	196_210	0,5	0,0	23,7	24,3	0,0	34,0
16	210_224	7,7	0,0	22,5	23,7	0,3	33,6
17	224_238	1,7	0,0	23,1	22,5	0,1	32,3
18	238_252	0,8	0,0	23,6	23,1	0,1	33,0
19	252_266	1,7	0,0	22,9	23,6	0,0	32,9
20	266_280	3,5	0,0	20,2	22,9	1,1	30,7
21	280_294	0,6	0,0	24,2	20,2	0,0	31,5
22	294_308	0,3	0,0	23,3	24,2	0,0	33,6
23	308_322	0,5	0,0	20,6	23,3	0,1	31,1
24	322_336	1,5	0,0	21,7	20,6	0,0	30,0
25	336_350	0,0	0,0	21,4	21,7	0,0	30,5
26	350_364	0,0	15,6	14,7	21,4	0,7	30,3

Table 5: Soil water storage $S_L(t_i)$, standard deviations $s(S_L)$, and coefficients of variation (CV) of each period analyzed.

Balance	Period	DAB	S_I							
			1	**2**	**3**	**4**	**5**	$\overline{S_L}$	**$s(S_L)$**	**CV**
1	01/09 to 15/09	0_14	250.2	260.8	203.4	254.6	257.2	245.2	23.7	9.7
2	15/09 to 29/09	14_28	261.0	271.1	221.0	265.6	268.3	257.4	20.7	8.0
3	29/09 to 13/10	28_42	255.9	265.6	213.1	259.3	262.4	251.3	21.6	8.6
4	13/10 to 27/10	42_56	272.3	284.5	242.8	303.0	286.9	277.9	22.5	8.1
5	27/10 to 10/11	56_70	269.9	280.3	232.8	292.2	279.9	271.0	22.8	8.4
6	10/11 to 24/11	70_84	263.2	276.0	221.5	278.7	276.8	263.3	24.1	9.2
7	24/11 to 08/12	84_98	273.0	287.4	238.7	296.3	282.5	275.6	22.3	8.1
8	08/12 to 22/12	98_112	286.3	306.7	262.3	317.2	293.1	293.1	21.0	7.2
9	22/12 to 05/01	112_126	277.9	299.8	249.8	309.2	288.0	284.9	22.9	8.0
10	05/01 to 19/01	126_140	288.3	312.9	271.4	336.9	299.9	301.9	24.8	8.2
11	19/01 to 02/02	140_154	288.0	311.4	270.2	328.0	303.2	300.2	22.1	7.4
12	02/02 to 16/02	154_168	380.0	380.2	324.5	384.3	380.6	369.9	25.5	6.9
13	16/02 to 01/03	168_182	352.1	354.8	302.6	359.5	350.8	344.0	23.3	6.8
14	01/03 to 15/03	182_196	375.4	382.3	317.4	375.2	375.3	365.1	26.9	7.4
15	15/03 to 29/03	196_210	356.2	364.1	305.4	359.2	357.7	348.5	24.3	7.0
16	29/03 to 12/04	210_224	310.5	314.4	258.0	311.5	306.0	300.1	23.7	7.9
17	12/04 to 26/04	224_238	304.5	317.2	261.9	315.4	305.2	300.8	22.5	7.5
18	26/04 to 10/05	238_252	305.0	313.3	261.0	318.2	309.2	301.3	23.1	7.7
19	10/05 to 24/05	252_266	301.0	306.4	253.0	308.7	305.4	294.9	23.6	8.0
20	24/05 to 07/06	266_280	300.2	304.8	254.3	306.1	308.8	294.8	22.9	7.8
21	07/06 to 21/06	280_294	360.1	359.9	312.8	356.2	354.3	348.7	20.2	5.8
22	21/06 to 05/07	294_308	348.4	348.7	293.3	342.0	348.7	336.2	24.2	7.2
23	05/07 to 19/07	308_322	327.7	327.7	274.8	321.6	329.2	316.2	23.3	7.4
24	19/07 to 02/08	322_336	350.7	345.4	306.0	353.7	355.3	342.2	20.6	6.0
25	02/08 to 16/08	336_350	341.4	334.6	290.7	337.9	341.7	329.3	21.7	6.6
26	16/08 to 30/08	350_364	334.1	324.3	280.4	322.9	327.4	317.8	21.4	6.7

Table 6: Runoff (RO), standard deviations (SD), and coefficients of variation (CV) from each period.

Balance	**Period**	**DAB**	**RO (mm)**					$\overline{RO}$ **(mm)**	**s(RO)**	**CV**
			1	**2**	**3**	**4**	**5**			
1	01/09 to 15/09	0_14	-	-	-	-	-	-	-	-
2	15/09 to 29/09	14_28	-	-	-	-	-	-	-	-
3	29/09 to 13/10	28_42	0.0	0.0	0.4	0.6	0.1	0.2	0.3	118.9
4	13/10 to 27/10	42_56	0.0	0.0	0.0	0.0	0.1	0.0	0.0	223.6
5	27/10 to 10/11	56_70	-	-	-	-	-	-	-	-
6	10/11 to 24/11	70_84	0.0	0.0	0.6	0.8	0.5	0.4	0.4	94.3
7	24/11 to 08/12	84_98	0.0	0.0	0.2	0.0	0.7	0.2	0.3	173.2
8	08/12 to 22/12	98_112	-	-	-	-	-	-	-	-
9	22/12 to 05/01	112_126	0.0	0.0	0.7	1.8	0.1	0.5	0.8	149.6
10	05/01 to 19/01	126_140	0.0	0.0	0.1	0.3	0.0	0.1	0.1	138.3
11	19/01 to 02/02	140_154	0.0	0.0	1.4	1.4	0.1	0.6	0.7	125.6
12	02/02 to 16/02	154_168	0.0	0.0	0.4	0.9	0.0	0.3	0.4	152.7
13	16/02 to 01/03	168_182	3.0	0.5	1.1	1.3	0.0	1.2	1.1	96.0
14	01/03 to 15/03	182_196	0.0	0.0	0.6	1.5	0.0	0.4	0.7	155.1
15	15/03 to 29/03	196_210	-	-	-	-	-	-	-	-
16	29/03 to 12/04	210_224	0.6	0.2	0.6	0.0	0.0	0.3	0.3	110.6
17	12/04 to 26/04	224_238	0.0	0.0	0.1	0.3	0.0	0.1	0.1	158.8
18	26/04 to 10/05	238_252	0.0	0.0	0.1	0.2	0.0	0.1	0.1	142.6
19	10/05 to 24/05	252_266	0.0	0.0	0.0	0.0	0.0	0.0	0.0	223.6
20	24/05 to 07/06	266_280	0.0	0.0	2.2	1.9	0.0	0.8	1.1	136.6
21	07/06 to 21/06	280_294	-	-	-	-	-	-	-	-
22	21/06 to 05/07	294_308	-	-	-	-	-	-	-	-
23	05/07 to 19/07	308_322	0.0	0.0	0.2	0.1	0.0	0.1	0.1	127.3
24	19/07 to 02/08	322_336	0.0	0.0	0.0	0.0	0.0	0.0	0.0	156.5
25	02/08 to 16/08	336_350	-	-	-	-	-	-	-	-
26	16/08 to 30/08	350_364	1.5	0.2	0.0	0.0	0.0	0.3	0.7	189.9
Sum	01/09 to 30/08	0_364	5,1	1,0	8,7	11,1	1,6	5,5	4,4	80,3

Table 7: Average values of rainfall ($\overline{P}$), irrigation ($\overline{I}$), soil water storage changes ($\overline{\Delta S}$), runoff ($\overline{RO}$), drainage ($\overline{Q_L}$), actual evapotranspiration ($\overline{ER}$), and potential evapotranspiration ($\overline{ET_C}$), for all analyzed periods.

Balance	Period	DAB	$\overline{P}$ (mm)	$\overline{I}$ (mm)	$\overline{S_i}$ (mm)	$\overline{\Delta S}$ (mm)	$\overline{RO}$ (mm)	$\overline{Q_L}$ (mm)	$\overline{ER}$ (mm)	$\overline{ET_C}$ (mm)
1	01/09 to 15/09	0_14	4.1	34.2	245.2	12.2	0.0	0.0	-26.1	-50.1
2	15/09 to 29/09	14_28	5.8	0.0	257.4	-6.1	0.0	0.0	-11.9	-61.2
3	29/09 to 13/10	28_42	77.8	0.0	251.3	26.6	-0.2	0.0	-50.9	-58.9
4	13/10 to 27/10	42_56	17.9	0.0	277.9	-6.9	0.0	0.0	-24.8	-71.5
5	27/10 to 10/11	56_70	25.3	0.0	271.0	-7.8	0.0	0.0	-33.1	-33.1
6	10/11 to 24/11	70_84	75.1	0.0	263.3	12.3	-0.4	0.0	-62.3	-62.3
7	24/11 to 08/12	84_98	89.7	0.0	275.6	17.5	-0.2	0.0	-72.0	-72.0
8	08/12 to 22/12	98_112	49.3	0.0	293.1	-8.2	0.0	0.0	-57.5	-57.5
9	22/12 to 05/01	112_126	85.6	0.0	284.9	17.0	-0.5	0.0	-68.1	-68.1
10	05/01 to 19/01	126_140	50.6	0.0	301.9	-1.7	-0.1	0.0	-52.2	-52.2
11	19/01 to 02/02	140_154	167.7	0.0	300.2	69.8	-0.6	-54.4	-42.9	-42.9
12	02/02 to 16/02	154_168	69.8	0.0	369.9	-26.0	-0.3	0.0	-95.5	-95.5
13	16/02 to 01/03	168_182	152.9	0.0	344.0	21.1	-1.2	-79.4	-51.2	-51.2
14	01/03 to 15/03	182_196	73.1	0.0	365.1	-16.6	-0.4	0.0	-89.3	-89.3
15	15/03 to 29/03	196_210	14.0	0.0	348.5	-48.4	0.0	0.0	-62.4	-62.4
16	29/03 to 12/04	210_224	65.2	0.0	300.1	0.7	-0.3	0.0	-64.2	-64.2
17	12/04 to 26/04	224_238	52.3	0.0	300.8	0.5	-0.1	0.0	-51.7	-51.7
18	26/04 to 10/05	238_252	23.2	0.0	301.3	-6.4	-0.1	0.0	-29.6	-29.6
19	10/05 to 24/05	252_266	25.5	0.0	294.9	-0.1	0.0	0.0	-25.6	-25.6
20	24/05 to 07/06	266_280	101.5	0.0	294.8	53.8	-0.8	-21.3	-25.6	-25.6
21	07/06 to 21/06	280_294	7.2	0.0	348.7	-12.4	0.0	0.0	-19.6	-19.6
22	21/06 to 05/07	294_308	1.9	0.0	336.2	-20.0	0.0	0.0	-21.9	-21.9
23	05/07 to 19/07	308_322	32.7	0.0	316.2	26.0	-0.1	0.0	-6.6	-30.2
24	19/07 to 02/08	322_336	44.6	0.0	342.2	-12.9	0.0	-18.5	-39.0	-39.0
25	02/08 to 16/08	336_350	0.0	0.0	329.3	-11.4	0.0	0.0	-11.4	-49.3
26	16/08 to 30/08	350_364	0.0	37.5	317.8	-8.9	-0.4	0.0	-46.1	-51.0
Sum	01/09 to 30/08	0_364	1312.8	71.6	7931.6	63.7	-5.5	-173.6	-1141.7	-1336.1

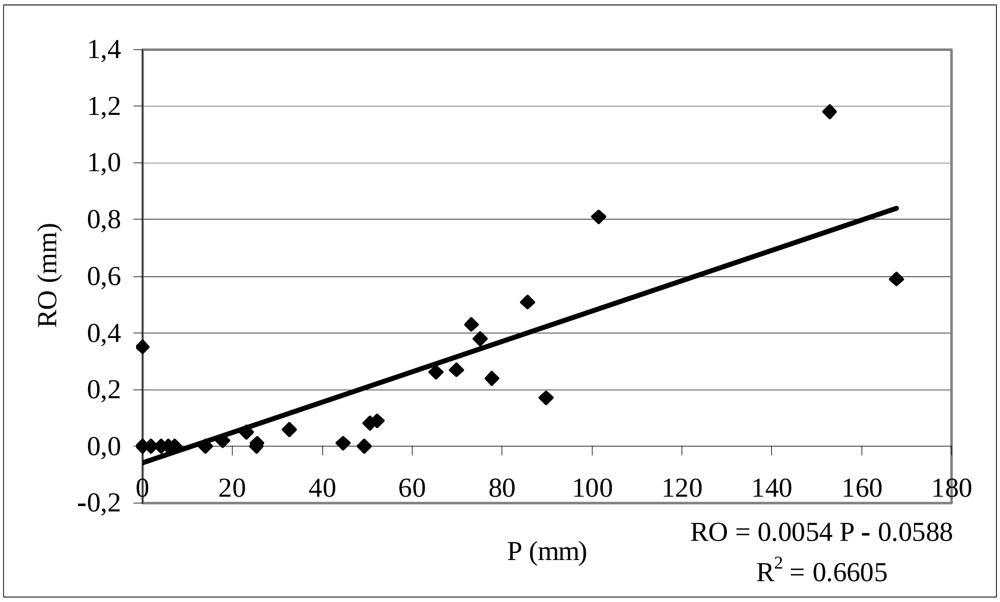

Figure 1: Variations in the runoff, RO (mm), as a function of the rainfall, P (mm).

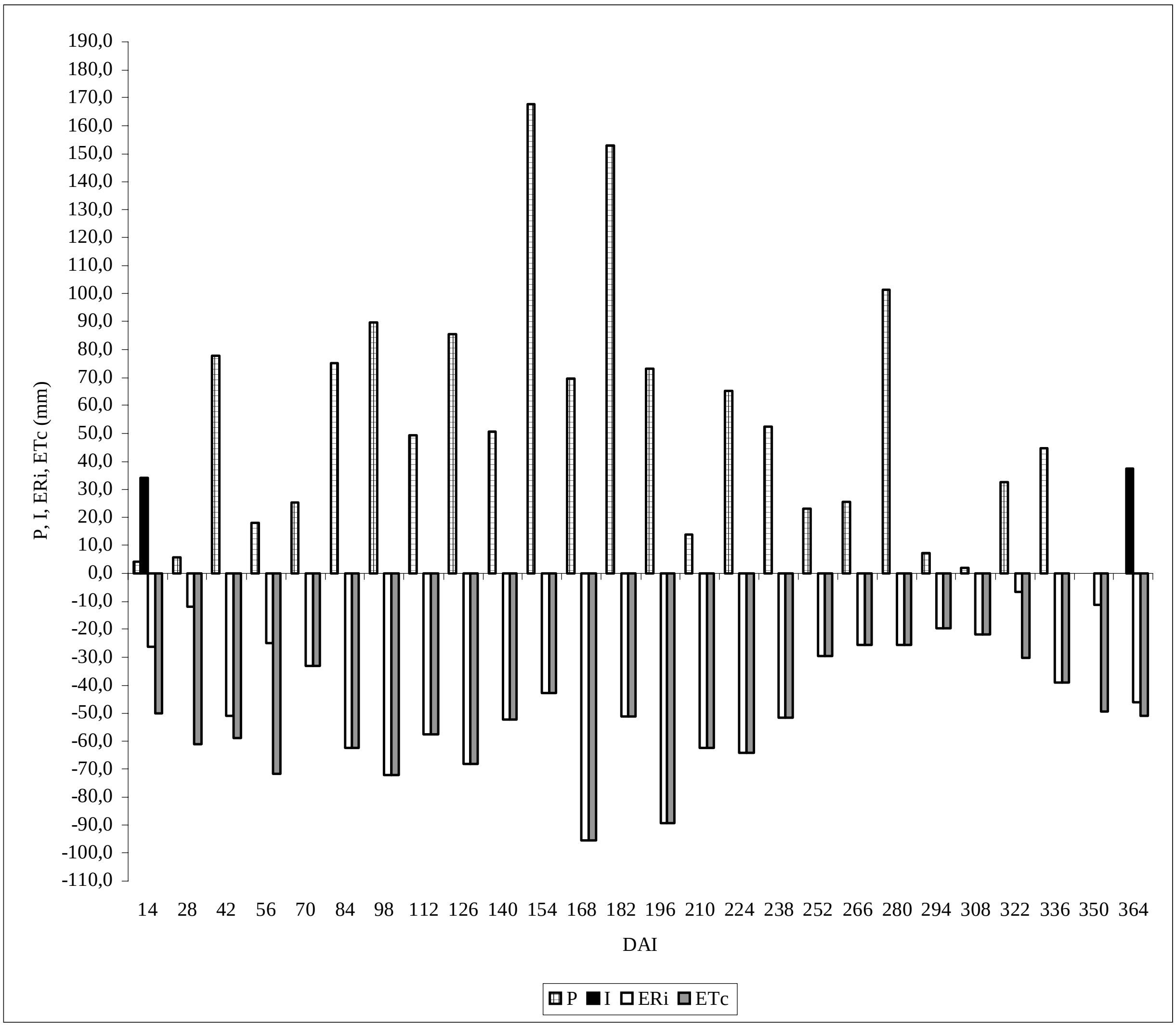

Figure 2: Variations in the rainfall (P), irrigation (I), actual evapotranspiration (ERi), and potential evapotranspiration (ETc), in mm,