EVAPORATION AND EVAPOTRANSPIRARION

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Evaporation is the water vapor loss through non living surfaces, like free water bodies and soil surface. **Evapotranspiration** is the loss though living organisms, in our case, the plant. The passage of water from the liquid phase to the vapor phase, which occurs below the boiling point, depends on the available energy that ultimately comes from the sun, and from other atmospheric conditions like air temperature and humidity, and wind. The average energy/ evaporation relation is 245 J mm^{-1} for temperatures in the range 10 to 30^{o} C. The process occurs even under no direct solar radiation presence, and in this case the energy is taken from the surrounding matter, like air, water itself, soil etc.

Potential Evapotranspiration (ET_0, mm) also called **Reference Evapotranspiration** (with symbols ETR, ET_r, ETP, ET_p), which is the water loss from a large green grass cover that occurs under conditions of no restriction of water availability. Under such conditions the atmosphere, through solar radiation, air temperature and humidity, and wind, regulates the process. It is also taken as an atmospheric potential of evaporation, in the sense that it can be calculated for situations even without the presence of water, e.g. Sahara desert. It characterizes the atmospheric demand of a region. A value of ET_0 = 12 mm, can be seen as a condition under which 12 mm of water would evaporate if water would be freely available.

Maximum Evapotranspiration (ET_m, mm) also called **Crop Evapotranspiration** (ET_c) is the same definition of ET_0 but for a crop different than grass, i.e., corn, soybean, cotton, forest, etc, because the loss of water depends on the cover. ET_m is related to ET_0 through a crop coefficient Kc:

$$ET_m = K_c \times ET_0 \quad (1)$$

K_c relates ET of a given crop to the ET of grass under the same atmospheric conditions. So, K_c has to be known, and data on K_c are widely available in the literature (ALLEN et al., 1998), for different crop management systems and growth stages.

Actual (or real) Evapotranspiration (ET_a, mm), which occurs at any moment of an agro-ecosystem, with or without water availability restriction. **Without restriction $ET_a = ET_m$, and under restriction $ET_a < ET_m$.** The soil can restrict the flow of water to its surface and to plant roots. Here Soil Physics plays an important role. Soil water retention and transmission characteristics control water movement in the soil.

There are several methods that estimate ET_0 or ETP from atmospheric data. **Thorntwaite** presented one of the first methods, based on air temperature only, that is widely used to date. The calculation of ETP_{TH} is based on the equation:

$$ETP_{TH} = f * 16 * \left(10 * \frac{Tn}{I}\right)^{a} \quad (2)$$

where is the temperature of month , in °C; the heat index of the region calculated according to Equation 4;   is a correction factor for latitude and month of the year (Table 1); and   is a regional thermal index calculated by Equation 5, in mm $month^{-1}$. The f factor is important to correct for the real number of days of each month.

To estimate ETp by **Penmam** (ETPp) the following equation is used:

$$ETP_p = \frac{W * R_n}{\lambda} + (1 - W)E_a \qquad (6)$$

where is the latent evaporation heat (MJ kg^{-1}); is a weight factor dependent on air temperature do ar (Equation 7); the net radiation (MJ m^{-2} d^{-1}); the evaporative air power (MJ m^{-2} d^{-1}).

By the **Penman-Monteith** method, ETPpm is calculated through:

$$ETP_{PM} = \frac{0{,}408\,\Delta\,(R_n - G) + \gamma \frac{900}{T_{med} + 273{,}16} U_2 * (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34 U_2)} \qquad (14)$$

where is the soil heat flux density (MJ m^{-2} d^{-1}).

As we have seen in our first lecture, these evapotranspiration definitions and estimations, can be used to calculate water balances (WBs). We give here as examples of climatologic WBs, the methods of Thornthwaite and Mather (THORNTHWAITE-MATHER, 1955), Rijtema and Aboukhaled (RIJTEMA; ABOUKHALED, 1975; DOURADO-NETO; DE JONG VAN LIER, 1993) and the Cossenoidal (DOURADO-NETO; DE JONG VAN LIER, 1993).

The main components of these balances are the evapotranspiration ET and the rainfall P. The difference P – ET is called first balance B, when positive indicating water excess EXC and when negative deficit DEF. Under deficit conditions the soil enters as a water source.

$$P + I - ETa = \Delta S + Q_L + R$$

1. B positive → water excess condition. Soil AWC is filled up and when full, excess of water $EXC = Q_L + R$
2. B negative → water deficit condition. Soil AWC is used until next rainfall.

Table 2 - An example of a Thornthwaite and Mather climatologic water balance sheet

Month i	ETPi	Pi	Bi	Li	Si	ΔSi	ETai	DEFi	EXCi
1	124,0	300	176,0	0,0	125,0	0,0	124,0	0,0	176,0
2	106,4	250	143,6	0,0	125,0	0,0	106,4	0,0	143,6
3	114,7	70	-44,7	44,7	87,4	-37,6	107,6	7,1	0,0
4	108,0	0	-108,0	152,7	36,8	-50,6	50,6	57,4	0,0
5	108,5	0	-108,5	261,2	15,5	-21,4	21,4	87,1	0,0
6	75,0	0	-75,0	336,2	8,5	-7,0	7,0	68,0	0,0
7	80,6	0	-80,6	416,8	4,5	-4,0	4,0	76,6	0,0
8	86,8	60	-26,8	443,6	3,6	-0,9	60,9	25,9	0,0
9	90,0	120	30,0	164,2	33,6	30,0	90,0	0,0	0,0
10	99,2	150	50,8	49,1	84,4	50,8	99,2	0,0	0,0
11	120,0	190	70,0	0,0	125,0	40,6	120,0	0,0	29,4
12	127,1	280	152,9	0,0	125,0	0,0	127,1	0,0	152,9
Year	1240,3	1420,0					918,1	322,2	501,9

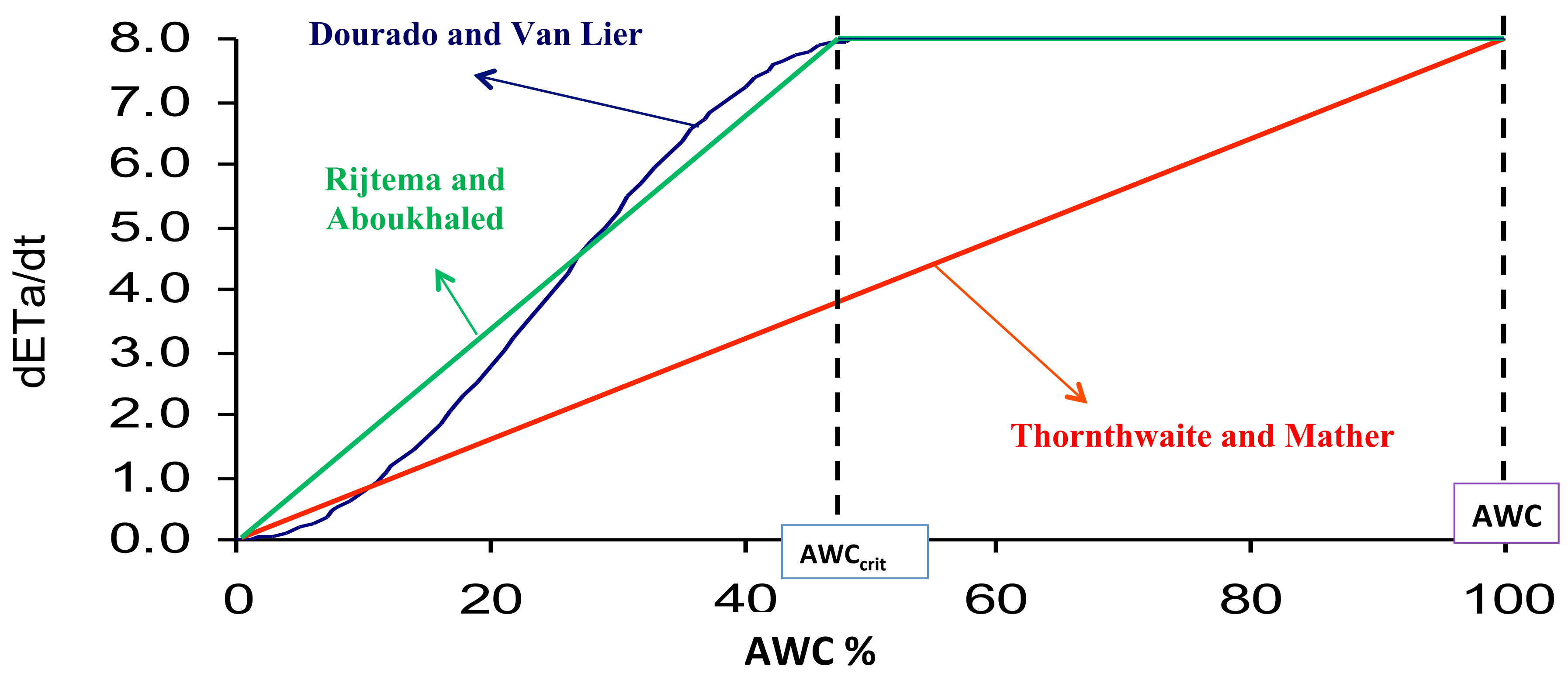


Figure 1 - Rate of soil water loss (dETa/dt, mm/period of time) as a function of storage (Arm, mm) for the methods of Thornthwaite and Mather, Rijtema and Aboukhaled and Dourado and Van Lier.

TEMPORAL VARIABILITY OF SOIL WATER STORAGE EVALUATED FOR A COFFEE FIELD.

Soil water storage (*S*) in agricultural soil profiles is an important parameter for a rational management of any crop, besides giving information on environmental aspects of the water cycle. Spatial variability of *S*, however, imposes serious problems when determining average values over large areas, which are needed to take actions in relation to water availability to crops. The variability of *S* is a consequence of the erratic rainfall input, differences in crop stand, and of natural soil matrix differences that can occur over short distances as well as over large fields due to soil genesis and topography. The knowledge of the characteristics of the variability of *S* helps to understand and predict several hydrologic processes (Western *et al,.* 2004) and to improve soil water sampling strategies (Warrick and Nielsen, 1980).

This study analyses the teporal variability of soil water storage (*S* mm) data collected in a coffee crop grown in Piracicaba, SP, Brazil (22º 42' 30'' S; 47º 38' 00' 'W, 580 m asl). Soil water contents *q* (*i*) were measured along a horizontal domain x_i (m) at 15 locations (i = 1, 2,…,15), and at five depths z_k (m), 0.2, 0.4, 0.6, 0.8, and 1.0 m from surface (k = 1, 2,…,5), every 14 days, at times t_j (j = 1, 2, 3,…,52) covering a two year period starting on September 01, 2003. Soil water content measurements obtained with a neutron probe (model CPN 503 DR).

To reduce the number of observation points so that future evaluations of the soil water status of this perennial coffee field could be made more rapidly and without losing accuracy, two approaches were used: i. making a time stability analysis to find out which access tube can represent the overall average of the field, and ii. establishing the minimum number of observation points that would yield an average value within a pre-established coefficient of variation. To verify the time stability of the measurements, the approach proposed by Vachaud et al. (1985) was used. For this, the relative deviation $\delta_j(i)$ % of each $\delta_j(i)$ realization in relation to the mean soil water storage $\overline{S_j}(i)$, was calculated as follows:

$$\delta_j(i) = \frac{S_j(i) - \overline{S_j}(i)}{\overline{S_j}(i)} \times 100 \qquad (2)$$

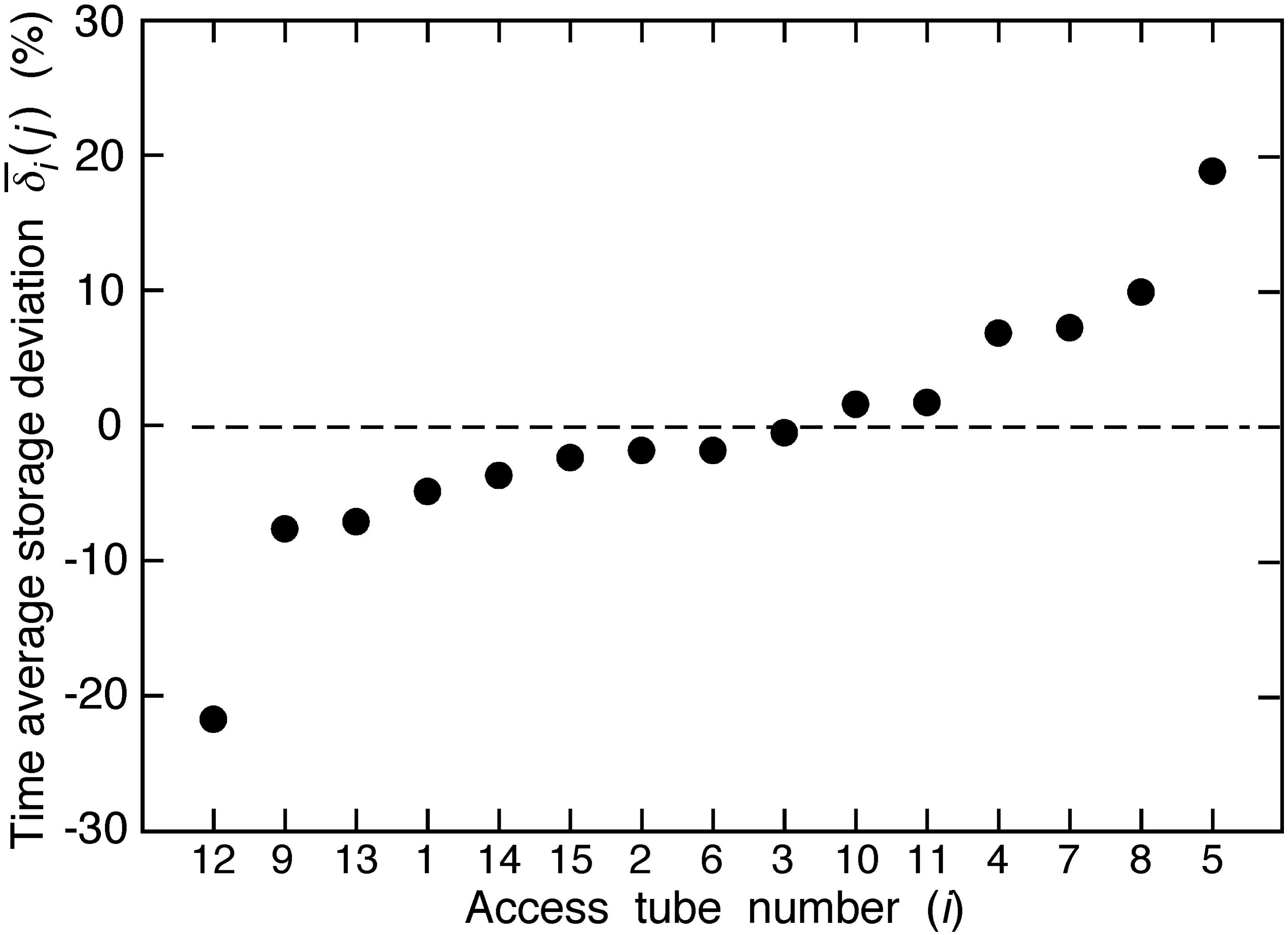


Figure 3 - Rank plots of time average relative spatial storage deviations

In a second step, the time variability structure of the s_j data was studied using the state-time approach (Shumway 1988; Nielsen and Wendroth 2003). The state-time analysis characterizes the state of a system (set of *p* unobservable variables) at a time *t* to its state at a time *t-j*, *j* = 1, 2, 3, …, 52, in our study. For *j* =1, the state-space approach is described as follows (called state equation):

$$X_t = \phi X_{t-1} + \omega_{X_t} \qquad (4)$$

X_t and X_{t-1} being the state vector (a set of *p* unobservable variables) at time *t* and *t* -1; *f* a *p* x *p* matrix of state coefficients, which indicates the measure of the regression; and noises of the system for *t* = 1, 2, 3,…, *j*.

$$Y_t = AY_{t-1} + \nu_{Y_t} \qquad (5)$$

the observation vector Y_t being related to the state vector X_t by an observation matrix *A* (usually known as, for instance, an identity matrix, *p* x *p*) and an observation noise vector ν_{Y_t}

According to Hui *et al.* (1998), if the X_t data are scaled with respect to their mean (m) and standard deviation (s), as follows:

$$x_t = [X_t - (m - 2s)]/4s \qquad (6)$$

the transformed values x_t become dimensionless with mean m = 0.5 and standard deviation s = 0.25. This transformation allows state coefficients of the matrix f have magnitudes directly proportional to their contribution to each state variable used in the analysis. The software Applied Statistical Time Series Analysis (ASTSA) (Shumway 1988) was used for applying the state-space approach.

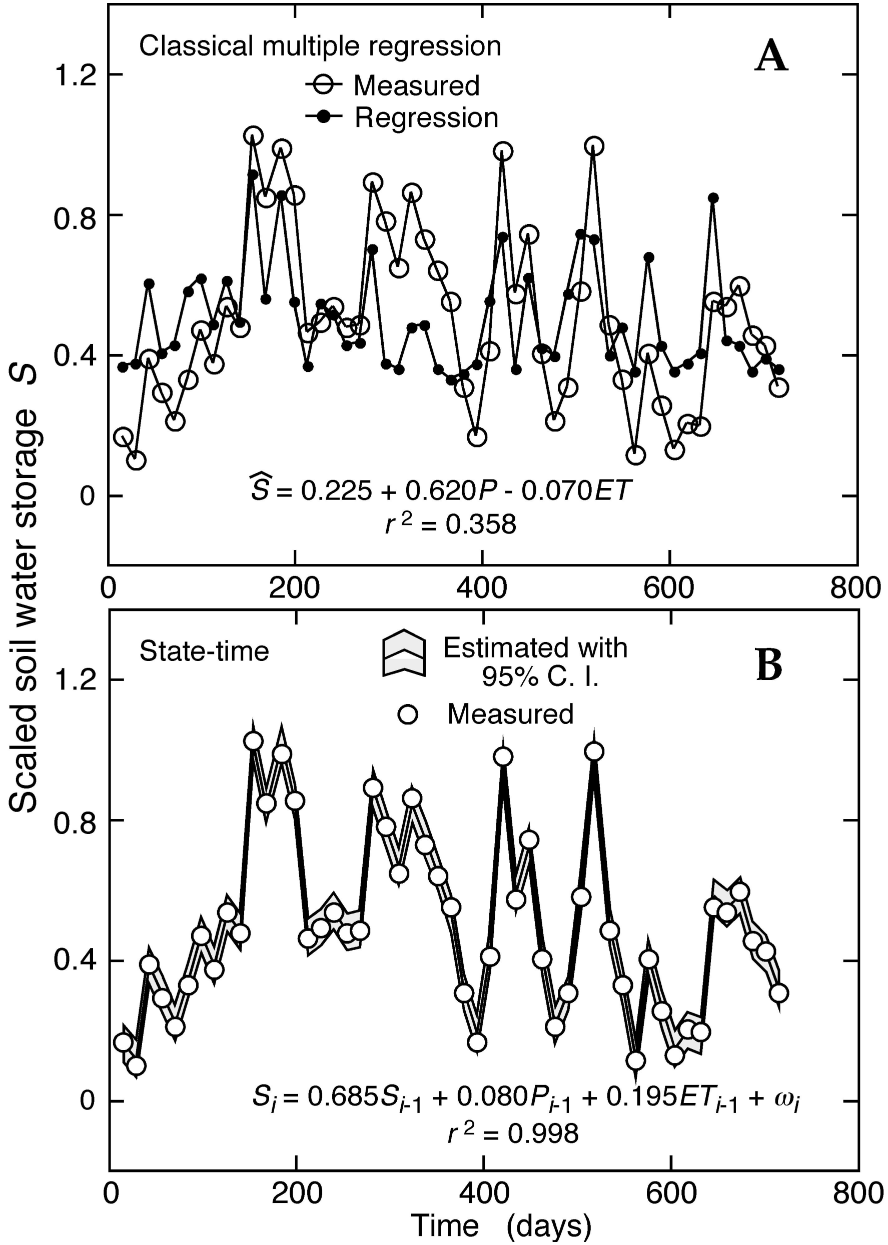


Figure 4 - Estimates of soil water storage measured biweekly for 714 days using A. classical multiple regression and B. state-time analysis.

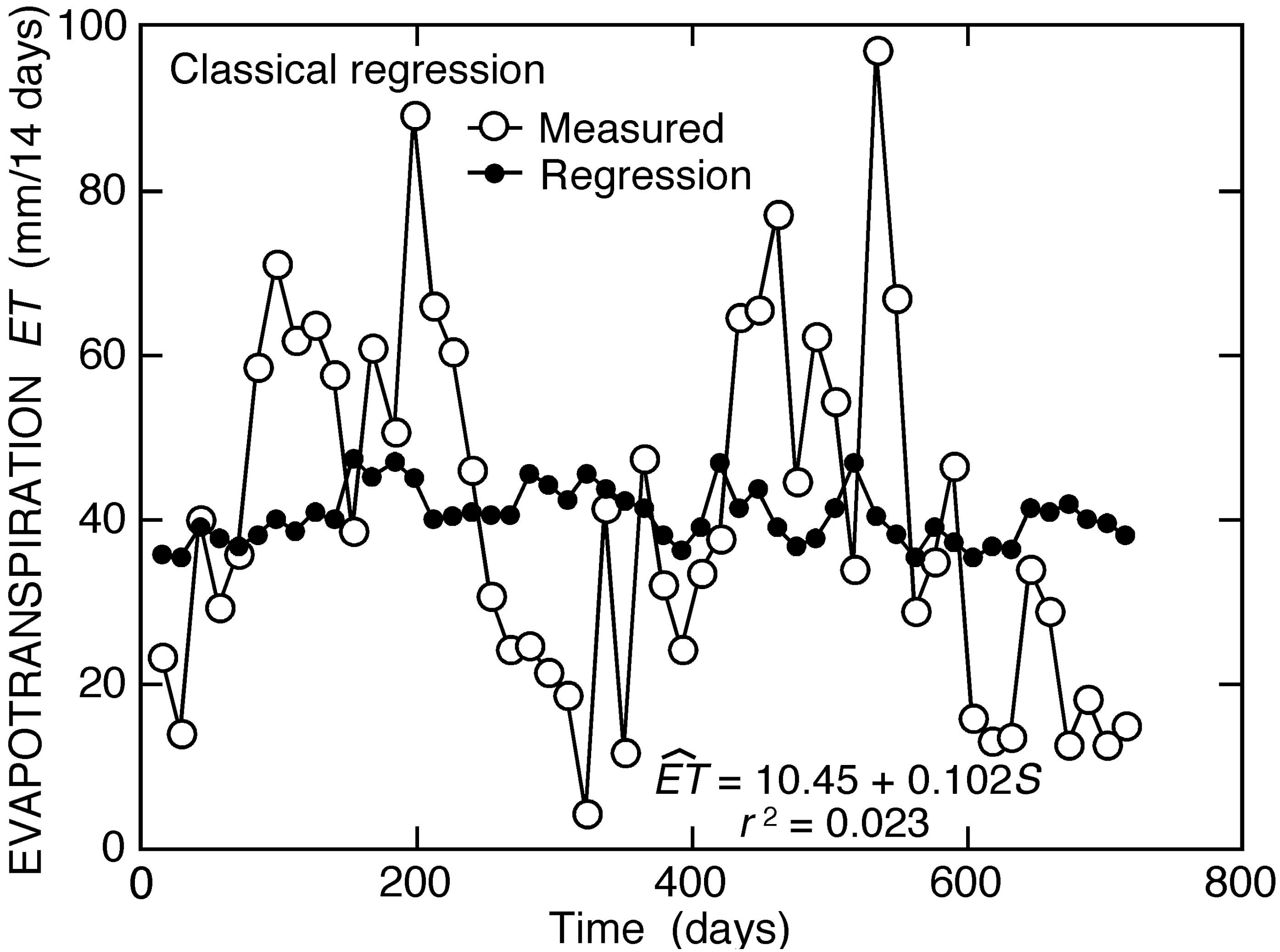


Figure 6 - Evapotranspiration measured biweekly for 714 days estimated using classical linear regression.

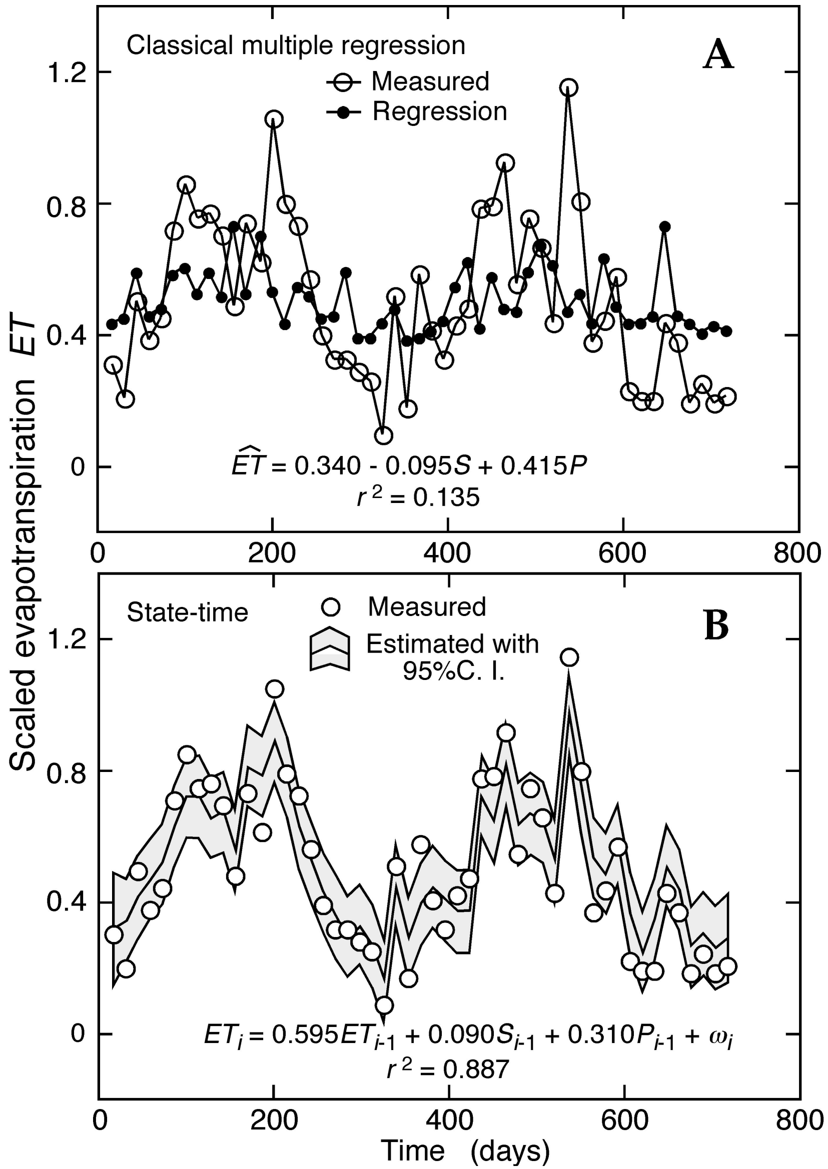


Figure 7 - Estimates of evapotranspiration measured biweekly for 714 days using A. classical multiple regression and B. state-time analysis.

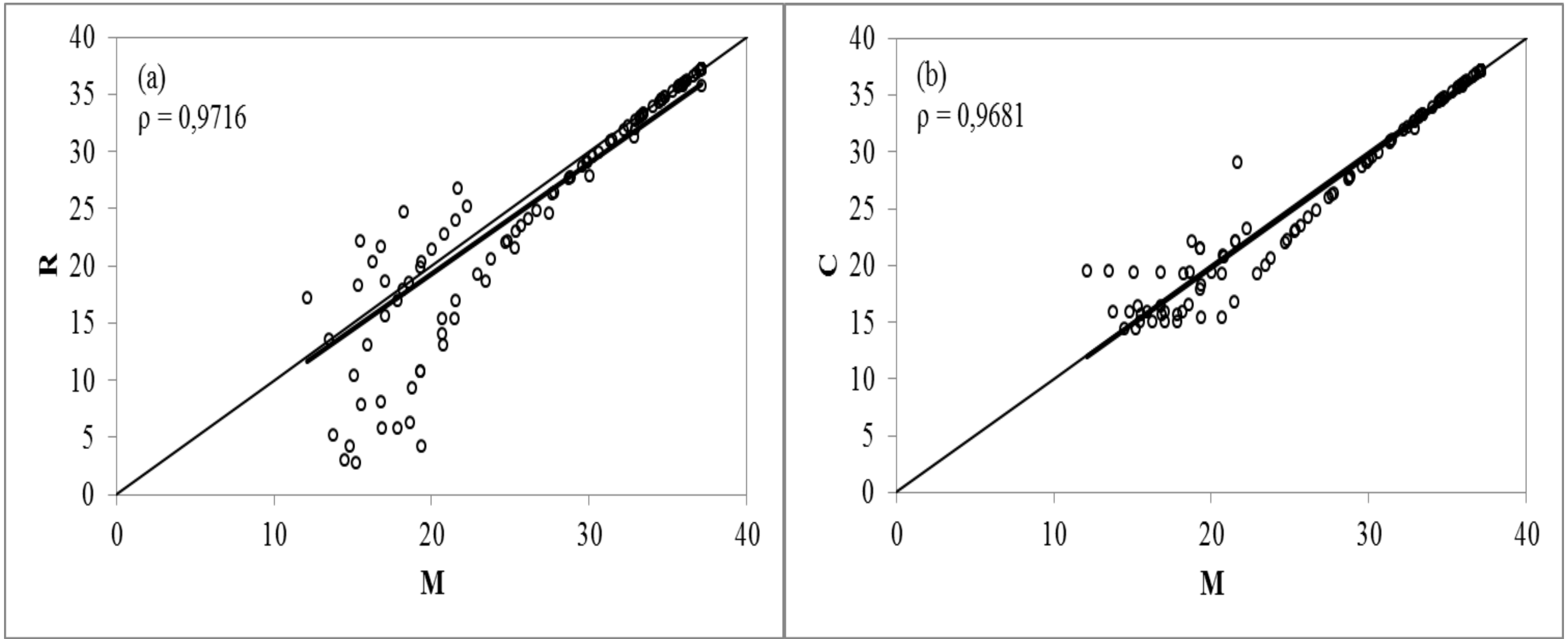
Conclusions

In contrast to classical multiple regression analysis, the state-time analysis showed that S_i was more dependent on $P_{i\text{-}1}$ (52%) than on $ET_{i\text{-}1}$ (28%) and $S_{i\text{-}1}$ (20%), indicating the low temporal dependence of S in relation to previous measurements. Additionally, the analysis showed that ET_i was not realistically estimated from $S_{i\text{-}1}$ measurements inasmuch as it was more dependent on previous estimations $ET_{i\text{-}1}$ (59%), than on $P_{i\text{-}1}$ (30%) and $S_{i\text{-}1}$ (9%). With P and ET easily obtained from automated weather stations, the state-time analysis indicated that S measurements made every 14 days could be reduced to monthly measurements, and that S_i measurements would still be predicted with an $r2$ of 0.957 – significantly reducing future field work.

SOIL WATER STORAGE CHANGES MEASURED IN A SOYBEAN CROP IN PIRACICABA, BRAZIL

A soybean (*Glycine max* (L.) Merrill) crop was established on na Oxisol in Piracicaba, Brazil, and for management pouposed the soil water storage S was monitored during the whole cycle. The novelty of the experiment was the continuous measurement of the soil water matric potential h (m) using polimer tensiometers. Readings of h were then transformed into ϴ through the use of a soil water retention curve, to further calculate water storages.

Figure 2. View of the soybean crop at initial growth stage. Piracicaba, 2012.



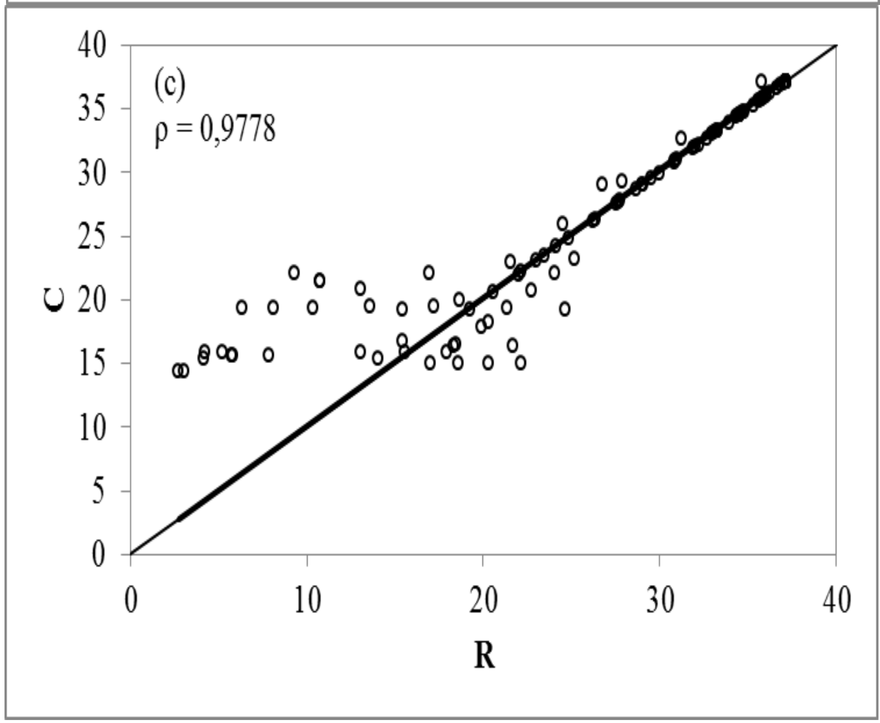


Figura 12 - Análise de regressão entre os armazenamentos de água estimados pelos métodos de balanço hídrico de: (a) Thornthwaite e Mather (M) e Rijtema e Aboukhaled (R); (b) Thornthwaite e Mather (M) e Cossenoidal (C); e (c) Rijtema e Aboukhaled (R) e Cossenoidal (C), com estimativa da ETC pelo método de **Thornthwaite**

VARIABILITY OF WATER BALANCE COMPONENTS IN A COFFEE CROP GROWN IN BRAZIL

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.

The experiment was carried out in Piracicaba, SP, Brazil, (22^{o}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 actual crop evapotranspiration (ETa) 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 (2), ETa, now named ETa', was overestimated because it includes Q_L. Thus, in periods in which ETa was larger than the potential evapotranspiration (ETm), ETa was considered equal to ETm and the difference ERa–ETm = 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 ETa 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.

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

Balance	DAB	$\overline{ETa'}$ (mm)	s(ETa')	CV	$\overline{ET_0}$ (mm)	K_C	$\overline{ETm}$ (mm)	ETa=ETa'-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