Revista Árvore
ISSN: 0100-6762
r.arvore@ufv.br
Universidade Federal de Viçosa
Brasil

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Revista Árvore, vol. 32, núm. 5, octubre, 2008, pp. 781-792
Universidade Federal de Viçosa
Viçosa, Brasil

COFFEE WATER USE IN AGROFORESTRY SYSTEM WITH RUBBER TREES[1]

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ABSTRACT – Water uptake and use by plants are essentially energy processes that can be largely modified by percentage of soil cover, plant type; foliage area and its distribution; phenological stage and several environmental factors. Coffee trees (*Coffea arabica* - cv. Obatã IAC 1669-20) in Agrforestry System (AFS) spaced 3.4x0.9m apart, were planted inside and along rows of 12- year-old rubber trees (*Hevea* spp.) in Piracicaba-SP, Brazil (22 42'30" S, 47 38'00" W - altitude: 546m). Sap flow of one-year-old coffee plants exposed to 35; 45; 80; 95 and 100% of total solar radiation was estimated by the heat balance technique (Dynamax Inc.). Coffee plants under shade showed greater water loss per unit of incident irradiance. On the other hand, plants in monocrop (full sun) had the least water loss per unit of incident irradiance. For the evaluated positions average water use was (gH2O.m^{-2}Leaf area.MJ^{-1}): 64.71; 67.75; 25.89; 33.54; 27.11 in Dec./2002 and 97.14; 72.50; 40.70; 32.78; 26.13 in Feb./2003. This fact may be attributed to the higher stomata sensitivity of the coffee plants under more illuminated conditions, thus plants under full sun presented the highest water use efficiency. Express transpiration by leaf mass can be a means to access plant adaptation to the various environments, which is inaccessible when the approach is made by leaf area.

Keywords: Water use, efficiency, coffee, rubber tree, light and transpiration.

USO DA ÁGUA EM SISTEMA AGROFLORESTAL COM CAFÉ E SERINGUEIRA

*RESUMO – A absorção e uso da água pelas plantas são processos essencialmente energéticos que podem ser grandemente modificados pela porcentagem de cobertura do solo, tipo de plantas, área foliar e sua distribuição, estágio fenológico e diversos fatores ambientais. Cafeeiros (**Coffea arabica** - cv. Obatã IAC 1669-20) em Sistema Agroflorestal (AFS) espaçados de 3.4 x 0.9 m foram plantados dentro e ao lado de um seringal de 12 anos de idade (**Hevea** spp.) em Piracicaba, SP, Brasil (22 42'30"S, 47 38'00" W - altitude: 546 m). O fluxo de seiva dos cafeeiros com 1 ano de idade expostos a 35, 45, 80, 95 e 100% da radiação solar foi estimado pela técnica do balanço de calor (Dynamax Inc.). Cafeeiros sombreados sofreram a maior perda de água por unidade de radiação incidente. No entanto, as plantas em monocultivo (pleno sol) apresentaram a menor perda de água por unidade de radiação incidente. Nas distâncias avaliadas, o uso médio de água foi (gH2O.m^{-2}área foliar.MJ^{-1}): 64,71; 67,75; 25,89; 33,54; e 27,11 em dez./2002 e 97,14; 72,50; 40,70; 32,78; e 26,13 em fev./2003. Tal fato pode ser atribuído à maior sensibilidade estomatal dos cafeeiros sob condições de maior iluminação, o que faz que plantas a pleno sol apresentem eficiência de uso da água mais elevada. Expressar a transpiração por massa de folha pode ser um meio de verificar a adaptação das plantas aos diversos ambientes, a qual é inacessível quando realizado por área foliar.*

Palavras-chave: Uso da água, eficiência, café, seringueira, luz e transpiração.

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[1] Recebido em 20.06.2007 e aceito para publicação em 22.08.2008.
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INTRODUCTION

Agroforestry System (AFS) is a land use system in which trees grow associated with other perennial or annual crops and/or cattle in various spatial and time arrangements, using management practices compatible with the local population. In that system, ecological and economic interactions between trees and other crops result in some advantages in comparison with other agricultural systems (NAIR, 1989; YOUNG, 1989).The AFSs can provide higher efficiency and ability to complement space and time in the use of the resources available to the production of water, nutrients, etc. Reduced density of shading trees planting or intercropping with shade-tolerant plants and more water- and nutrient-competitive plants can enhance the efficiency of the AFSs, thus increasing production sustainability.

The presence of trees in a production system can change the radiation balance and wind behavior in the area under their influence (MONTEITH et al., 1991; BRENNER, 1996). Trees act in the environment in three ways: i) partially and temporarily shading the protected crop; ii) competing for water and soil nutrients, and iii) reducing wind speed. This way, the microclimate undergoes changes which lead to different physiological processes and characteristics of the protected crop (LEAL, 1986). The multiple effects of these microclimatic changes modify the balance of the energy available to the environment, resulting in changes in the water use, productivity and cycles of plants under such condition (BALDY and STIGTER, 1993).

Physiologists and ecologists have long reasoned that understanding the processes and mechanisms involved in capturing resources and use of the related interactions with the environment is of utmost importance for the development of sustainable productive systems (WILLEY and REDDY, 1981; ONG et al., 1996; LIMA JR. et al., 2006).

AFS species share many processes, including competition, environmental change, and nitrogen transference to associated nonlegumes. Ong et al., (1996) report that underground interactions have been important in AFSs, and special attention should be given to studies focussing on the use efficiency of natural resources. According to Sá (1994), the AFSs provide great improvement in water use in semi arid regions and arid tropics where availability is seasonal. Most annual crop systems use only 30 to 35% of rain water, and the remaining is wasted through soil evaporation, surface runoff, or is lost in residual humidity at the end of harvest. AFSs provide the opportunity of complementing water use both spatially and temporally, which can result in better water use in comparison with single crops (ONG et al., 1996).

Nuberg et al. (2002) observed no benefits to intercrops due to improved micrometeorological conditions in tropical rain regions. Likewise, Crawford et al. (1998) point examples of intercrop yielding not reduced by competition with trees in high rainfall regions. On the other hand, several authors (KANG, 1993; SANCHEZ, 1995; GOVINDARAJAN, et al., 1996; STIRZAKER et al., 2002) assert that in limited water environments, alley AFSs tend to have a negative effect on grain production of associated crops more frequently than a neutral or positive one. Ong (1994) points that the focus in AFSs in alley should, therefore, be on minimizing the negative effects instead of seeking sudden production gains.

In the various vegetation types found in nature, productivity is closely related to the water available to plants (SALISBURY and ROSS, 1991). Among the plant production limiting factors, water deficit is outstanding, in that besides affecting the water relations in plants and modifying the metabolism, it is a phenomenon occurring in large cultivated areas. Many plants, according to Boyer (1982), have mechanisms capable of decreasing the effects of lacking soil water and likely to be genetically transmitted.

Mazzafera and Carvalho (1987) state the importance of correlating coffee plant productivity and water deficiency conditions, since many drought-tolerant progenies present low production. The same authors found a slight reduction in coffee photosynthesis under water potential of up to -2.0 MPa, suggesting that coffee is a relatively drought-resistant species.

The cultivation of shaded coffee in Brazil has not been generalized due to the fact that low coffee productivity is attributed to water competition with shading trees (FRANCO, 1963).

For the understanding of the water transference dynamics in forest communities, the transpiration measure is essential (GRANIER, 1985). In addition, it plays an important role in the plant's energy balance with the environment and carbon dioxide uptake for photosynthesis (ANGELOCCI, 2002). The determination of xylem water flow has drawn great attention, especially in trees, been field measurement always difficult. Among the methods to be employed, the Heat Balance method - balance of dissipated heat in a given stalk or branch volume through continuous and constant heat flow - has been successfully used (SAKURATANI, 1981; VALANCOGNE and NASR, 1989; WEIBEL and VOS, 1994).

Energy and gas exchanges between plant and environment is determined especially by leaves, supported and arranged under branches and trunks to ensure an efficient transference (OLIVEIRA et al., 2006; CAMPBELL and NORMAN, 1989). When the stomatal opening is reduced, the transpiration is modified to a larger extent than the CO_2 flow, therefore photosynthesis as well. The stomata will only close, interrupting gas exchanges, in extreme cases in which the water loss tends to compromise the remaining physiological functions of the plant (ANGELOCCI, 2002). A plant's ability to moderate water loss while keeping enough CO_2 uptakes for photosynthesis can be analyzed by means of a parameter called transpiration ratio (TAIZ and ZEIGER, 1991), or water requirement (KRAMER and BOYER, 1995), defined as the amount of water transpired by the plant divided by the amount of carbon dioxide assimilated through photosynthesis. The opposite of the transpiration ratio is called 'water use efficiency' (WUE) (TAIZ and ZEIGER, 1991). WUE is then defined as a dry matter unit produced per plant, per unit of used water (KRAMER and BOYER, 1995). Therefore, since the WUE is a relation between CO_2 uptake (A) and transpiration (T), one can firstly say that if the water availability is reduced, the stomata are closed and transpiration decreased, raising the WUE (TAIZ and ZEIGER, 1991). Great evidences point that the WUE varies among species, within the same environment, and among climates to a same crop (KRAMER and BOYER, 1995). Various studies have shown that in a given species, the transpiration/ photosynthesis ratio remains roughly constant with the variation of the stomatal conductance in response to the changes in irradiance, relative humidity, hydric stress, soil fertility and CO_2 concentration (FARQUHAR, 1979; HALL and SCHULZE, 1980; FIELD et al., 1982; MOONEY et al., 1983).

Givinish (1988) suggests that studies focussing plant adaptation to shade must be directed to roots, branches and leaves and must incorporate the effects of water and nutrient supply to determine the plant's ability to outlive a given environment.

For Givinish (1988), the photosynthetic benefits due to CO_2 diffusion increases to the inner leaves must be considered according to the energy costs associated to increased water losses. Transpiration costs must take into account the reduction of the mesophyll photosynthetic ability in view of the reduced leaf hydric potential, increased resource allocation to nonproductive tissues as roots or xylems, and, should that be the case, a reduction in the photosynthetic activity period ((GIVINISH and VERMEIJ, 1976; GIVINISH, 1984).

Leaf construction costs (C) are hard to measure for it scopes not only the costs in carbon fixing (P) in synthesizing the various components. It scopes the costs of construction and maintenance of roots and branches required to achieve nutrient and water in the leaf components synthesis (MOONEY and GULMON, 1979). The net return rate per investment unit in the leaf tissue is an important determinant in the growth rate of plants (GIVINISH, 1988). Thus, the same author suggests that from an economical view point, rather than expressing photosynthesis by area unit, it should be done so by mass unit (or maybe by leaf nitrogen content). Leaf construction costs per area unit must approximate leaf biomass by area unit ($^{1}/_{SLA}$ - Specific Leaf Area), provided that they do not vary much in composition (OSMOND et al., 1980). This way, the photosynthesis/production costs ratio (P/C) would be directly proportional to the photosynthesis per leaf mass unit (GIVINISH, 1988).

It is very important to have a better understanding of the coffee ecophysiological behavior in an AFS and at full sun, in order to increment the system's productivity, as well as to verify the possibility of using coffee as a complementary crop, thus optimizing the use of available resources.

The goal of this study is to improve the understanding of water use by coffee plants considering the microclimatic condition changes due to the presence of trees (shaded) and without their interference (full sun).

MATERIAL AND METHODS

The experiment was conducted in the experimental field of the Department of Crop Science of the Escola Superior de Agricultura "Luiz de Queiroz", University of São Paulo (ESALQ/USP) in Piracicaba-SP (22 42'30"S, 47 38'00"W - altitude 554m) during the years 2002 and 2003. The rubber tree field was planted in 1991 at a 8x2.5m spacing, with seedlings grafted in plastic bags with two mature leaf projections of the graft, with all experimental blocks composed of trees from the same clone - PB-235. Coffee was planted at 3.4x0.9m spacing during the first half of January 2001, under the rubber plantation, interfacing with trees and in monocrop. One used cultivar Obatã IAC 1669-20 - Mundo Novo. The seedlings were 9-month old and derived from direct seeding in plastic bags in a nursery with an adequate screen cover.

The land, with approximately 0-1.5% slope, is a structured eutrophic, moderate A horizon and clayey-textured, American classification Kandiudalfic Eutrodox. The soil fertility and the irrigation system set up in the trial area prevented limited growth and development of plants other than those deriving from the experimental treatment. In developing the coffee plants, soil analysis was performed for necessary amendments.

The experiment was totally randomized with 5 treatments - irradiance levels given by the distance from the edge of the trees - and in monocrops planted within the same spacing, weed-free and with no interference from the rubber trees. The 5 treatments included tree distances measured from the first row of rubber trees interfacing with the coffee plantation (zero distance). Negative distances refer to plants on the inside of the rubber tree plantation and the positive distances refer to the distance towards the monocropped coffee. Thus, the treatments used were the distances of -5.7; 1.5; 4.9; 11.7m from the trees edge and in monocrop (Figure 1). Statistical analyses were performed using the SAEG 7.0 statistical program (SAEG, 1997). The first row of rubber trees interfacing the coffee crop represents double rows of trees in an alley cropping agroforestry system.

Drip irrigation was used in the coffee plantation. The evapotranspiration was estimated by means of Class A tank, of the Main Meteorological Station of the Department of Exact Sciences, ESALQ-USLP, located next to the experiment. The irrigation depth was calculated according to the method proposed by Villa Nova and Sentelhas (1999).

The total leaf area of each coffee plant was obtained by counting the number of leaves multiplying by the size of the average leaf corrected. Each average leaf is equivalent to 68% of the rectangular area calculated according to its measures. The specific leaf area (SLA - $m^2.kg^{-1}$) was achieved by dividing the leaf area of 10 leaves randomly collected, with three replications per row, by its dry mass in an oven at 75 º C until constant weight.

Light condition above coffee plant canopies was continuously measured by solarimeter tubes (TS-UM-3, Eijkelkamp) installed at the same distance evaluated and connected to a data acquisition system (Delta-T Devices) set up in the experimental field. These measurements allowed estimating light transmission and uptake by trees and availability to coffee plants.

Coffee sap flow was estimated by the heat balance method through Dynamax Inc. sensors installed in coffee plant trunks (sensors models SGA 10 and SGB 25) and connected to a data acquisition system, model CR10X - Campbell Scientific Inc. in the periods of Dec. 6-11, 2002 and Feb. 16-25, 2003. The sensors were installed at distances of -5.7; 1.5; 4.9; 11.7 and one in monocrop (50m). Such method is based on the application of heat into a trunk segment and measuring the losses by axial (upward and downward) and radial (a constant is assumed for the energy flow migrating towards the inner plant according to its constitution) conduction and the variation of the thermal energy stored. The sap flow is therefore determined by balancing these losses and the power applied. An accurate technique with a good dynamic response (ANGELOCCI, 2001). This is one of the most frequently used methods in that it does not require calibration (ANGELLOCCI and VALANCOGNE, 1993).

RESULTS AND DISCUSSION

As presented in the previous paper of this series (Measurement and simulation of solar radiation availability related to growth of coffee plants in agroforestry system with rubber trees), the available radiation fraction increased as the distance among trees increased and can be described by the mathematical model proposed by Goudriaan (1977). The use adequacy of this mathematical model in the estimation of radiation availability to intercropping was confirmed by Righi (2000); Bernardes et al. (1998) and Castro and Bernardes (2000). The latter authors proposed a modification in the original calculus achieving a better approximation. An in-depth discussion on the changes of coffee plant canopy structures accordingly influencing light capture and growth can be found in the same work previously mentioned.

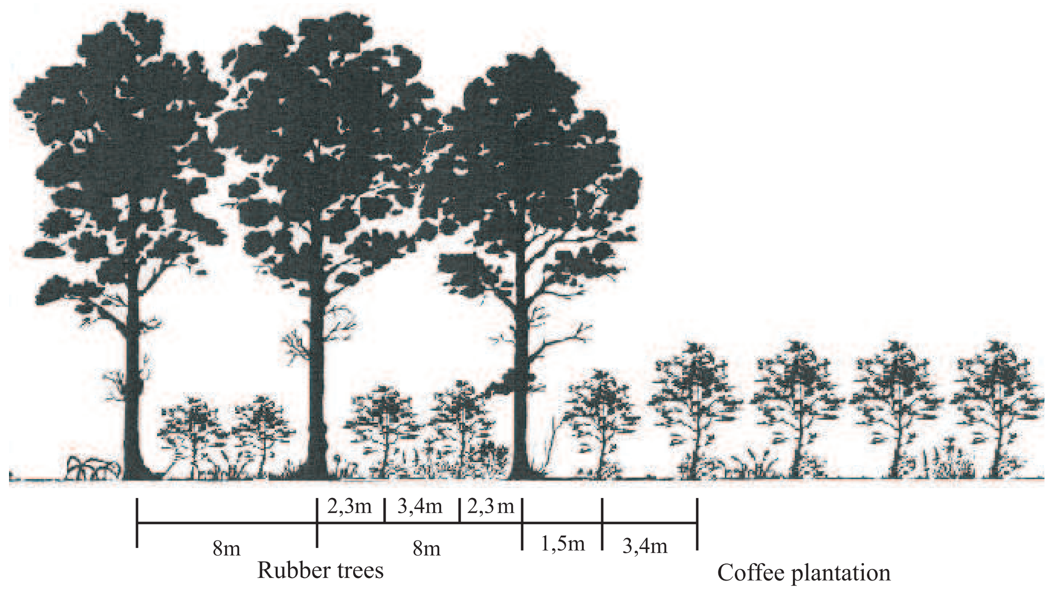

Figure 1 – Cross-section of the experimental field showing the arrangement of rubber trees and coffee plants.
Figura 1 – *Corte transversal do experimento de campo mostrando a disposição das seringueiras e cafeeiros.*

The relative solar radiation availability (I/I_0) to the coffee plants at evaluated distances from the rubber trees plantation - counting from the border: (inside) -5.7; (next to the rows) 1.5; 4.9; 11.7m and in monocrop were respectively: 35; 45; 80; 95% and 100%.

Although there is a time lag between transpiration and water reposition indicated by the sap flow, since all coffee plants were irrigated and the soil kept close to the field capacity, one assumes that the total sap flow observed was equivalent to the total transpired along the day. The sap flow estimated had a similar variation pattern in all positions evaluated within the same day, however, the total flow was greatly different among the positions and between days for a same position (Figure 2a).

Unlike the expectation, coffee plants exposed to full sun even with a larger total leaf area and under adverse micrometeorological conditions (excessive radiation, wind, etc.) had a relative low sap flow during the period evaluated, in comparison with more tree-protected coffee plants (Figure 2a). There are also great variations inherent to each individual plant nearly making direct comparisons impossible. This would certainly lead to false conclusions, as it is necessary its reduction to comparable values, such as dividing it by each plant's leaf area, resulting in significant changes in data interpretation (Figure 2b). Thus, when transpiration is divided by the leaf area one can observe changes in the relative sap flow arrangement of each position.

One should emphasize that at no moment during the day, even during the peak of the summer in the southern hemisphere (December/22 - summer solstice), did the sap flow of coffee plants cease. It is possible to observe at Figures 2a and 2b that plants presented two transpiration peaks apart from each other by a small reduction at mid-day 12:00 to 14:00 hs). This is in partially in accordance with Carelli et al (2000), who observed an increased sap flow density of coffee plants with increased irradiance.

Coffee plants at -5.7m receiving only 35% of the total solar radiation presented the smallest transpiration per leaf area during the day with a slight increase at about 16:00 hs (Figure 2b). In all positions coffee plants presented an abrupt decrease on transpiration stating at about 16:30 to 17:00 hs ceasing it early night reaching its minimum at 19:30 to 20:00 hs. Exception is made to plants at 4,9m distant (80% I/I_0) that presented a slow and continuous reduction on transpiration since 14:00 hs. Plants at 1.5m (45% I/I_0), 11.7 (95% I/I_0)) and in monocrop (100% I/I_0) presented similar variation patterns besides transpiration of the ones in monocrop was situated in a lower landing.

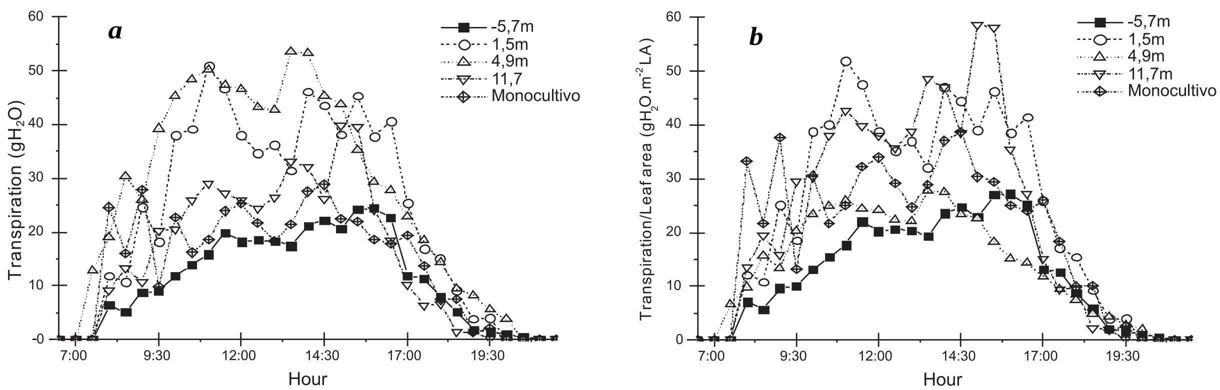

Figure 2.a – Coffee plants sap-flow (gH_2O) and b. sap-flow per leaf area (g$H_2O.m^{-2}$Leaf area), in December 6th 2002. Each line represents one plant at its distance from the rubber tress (5.7; 1.5; 4.9; 11.7m and in monocrop) - see legend.

Figura 2.a *– Fluxo de seiva dos cafeeiros (gH_2O) e b. Fluxo de seiva por área foliar (g$H_2O.m^{-2}$área foliar), em dezembro de 2002. Cada linha representa uma planta nas distâncias das árvores de seringueira (-5,7; 1,5; 4,9; 11,7m e em monocultivo) - ver legenda.*

As well explained by Givinish (1988) about the adequacy of expressing photosynthesis by leaf mass unit and given its close connection with water loss, in our assessment, expressing transpiration per leaf mass unit thus encompassing energetic costs per inference is convenient and elucidative.

Figure 3 presents coffee transpiration in several positions in the months of December/2002 and February/2003. Water loss values (sap flow - g$H_2O.day^{-1}$) were divided by the total leaf area (TLA- m^2) of each plant (Fig. 3a and d); by the leaf mass obtained by its relation with the specific leaf area (SLA $m^2.kg^{-1}$) (Fig. 3b and e); and by the incident radiation (MJ) measured by the solarimeter tube in the mentioned position (Fig. 3c and f).

When divided by the TLA (m^2), the sap flow values presented a gradual increase with the trees distance towards monocropping in both periods evaluated (Fig. 3a and d), with a slight inflection around 10m away. In Dec/2002, the lowest values were obtained -5.7m away from trees (inner rubber tree plantation), however, with a large increase in Feb/2003, when it was nearly equal to the monocrop values. The values observed (g$H_2O.m^{-2}$Leaf area.day^{-1}) were on average: 288.99; 467.28; 319.69; 490.78; 421.93 in Dec/2002 and 495.54; 590.71; 579.25; 559.99; 472.12 in Feb/2003 for distances of -5.7; 1.5; 4.9; 11.7m and in monocrop, respectively. Differently, when the transpiration was divided by the leaf mass (g) (Fig. 3b and e), the trend was exactly opposite, which is made clearer in the month of Feb/2003 (Fig. 3e). The mean values observed (g$H_2O.g^{-1}$Leaf mass.day^{-1}) were: 4.53; 5.02; 3.34; 4.87; 3.87 in Dec/2002 and 7.78; 6.34; 6.05; 5.56; 4.33 in Feb/2003 for the same distances. The same variation pattern can be observed in both months analyzed, when the transpiration per leaf area (g$H_2O.m^{-2}$Leaf area.day^{-1}) was reduced by the available radiation (MJ) in each of the evaluated positions. The clear transpiration decrease (g$H_2O.m^{-2}$Leaf area.MJ^{-1}.day^{-1}) followed an inverted exponential towards monocrop (Figure 3c and f), represented here by the 50m distance. Coffee plants under shade showed a higher water loss per unit of incident irradiance. On the other hand, plants in monocrop (full sun) performed the lowest water loss per unit of incident irradiance. For the evaluated positions the average water use were: 64.71; 67.75; 25.89; 33.54; 27.11 g$H_2O.m^{-2}$Leaf area.MJ^{-1}.day^{-1} in Dec/2002 and 97.14; 72.50; 40.70; 32.78; 26.13 g$H_2O.m^{-2}$Leaf area.MJ^{-1}.day^{-1} in Feb/2003. The replication of the variation patterns during the evaluated days and in both months indicates constant trends.

Despite the lower total transpiration of plants under intense shading (-5.7m), such plants showed higher transpiration values per leaf mass (g$H_2O.g^{-1}$Leaf mass.day^{-1}). This is due to the fact they present lower TLA and higher specific leaf area (SLA - m^2Leaf.kg^{-1}Leaf, 15;71; 10;75; 10;45; 9;93; 9;17 for distances of -5.7; 1.5; 4.9; 11.7m and in monocrop, respectively), which means thinner and larger leaves. Changes in

SLA values constitute an important plant feature, and are commonly found in species adapted to different luminosity conditions, as reported by several authors (ESAU, 1977; FAHL, 1989; RIGHI, 2000; PEREIRA, 2002).

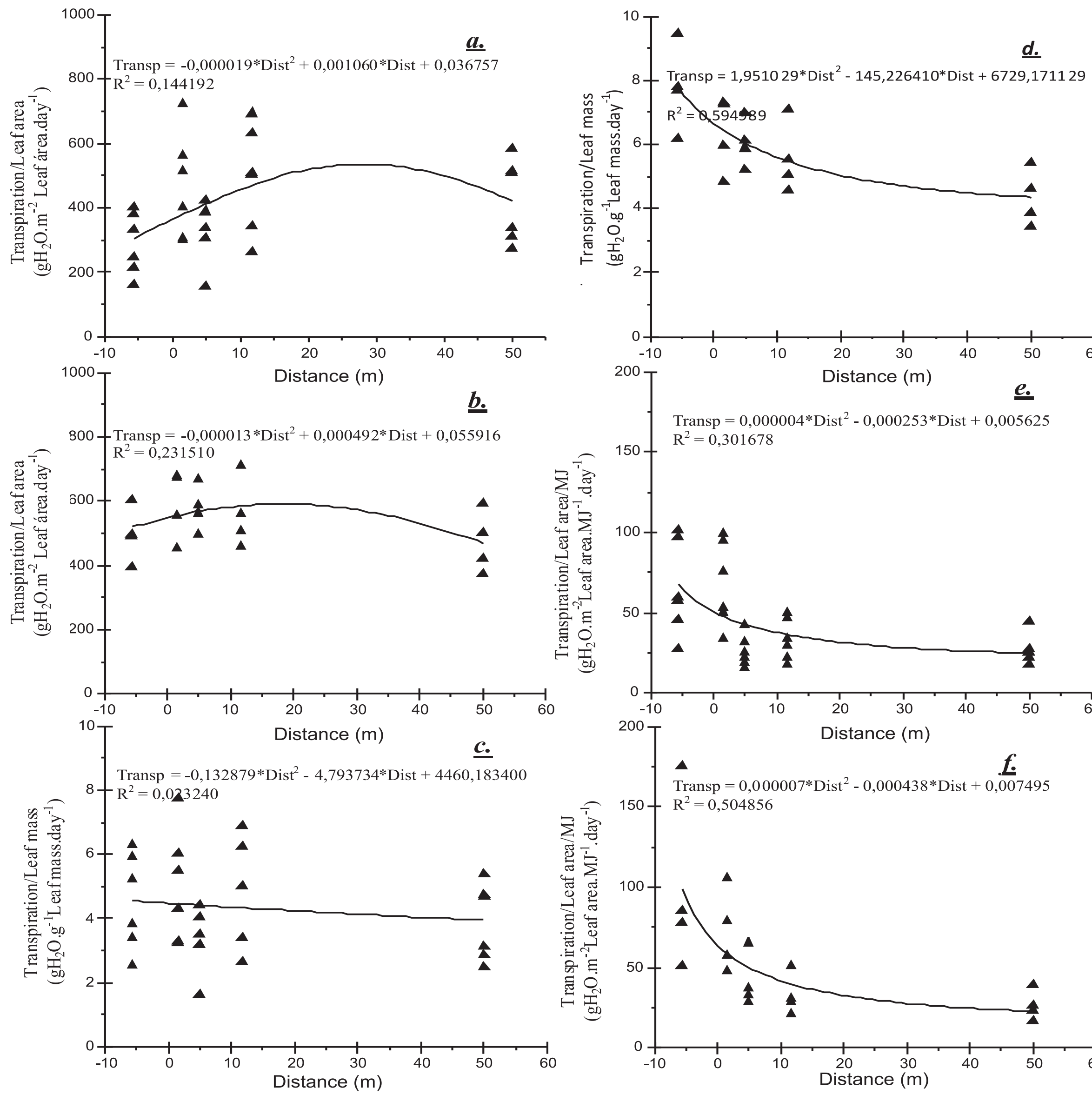

Figure 3 – a and b. Coffee plants sap-flow per leaf area ($gH_2O.m^{-2}$Leaf area.day^{-1}) in the periods of Dec. 6-11, 2002 and Feb. 16-25, 2003 respectively at distances of -5.7; 1.5; 4.9; 11.7 from rubber trees and one in monocrop (50m). c and d. Coffee plants sap-flow per leaf mass ($gH_2O.m^{-2}$Leaf mass.day^{-1}) as described before. e and f. Coffee plants sap-flow per leaf area and MJ ($gH_2O.m^{-2}$Leaf area. MJ-1.day^{-1}) as described before.

Figura 3 – a e b. Fluxo de seiva dos cafeeiros por area foliar ($gH_2O.m^{-2}$Leaf area.day^{-1}) nos períodos 06 a 11 de dezembro de 2002 e 16 a 25 de fevereiro de 2003, respecitivamente nas distâncias de -5,7; 1,5; 4,9; 11,7 das árvores de seringueira e uma em monocultivo; c e d. Fluxo de seiva dos cafeeiros por massa de folha ($gH_2O.m^{-2}$Leaf mass.day^{-1}) como descrito antes; e e f. Fluxo de seiva dos cafeeiros por área foliar MJ. ($gH_2O.m^{-2}$Leaf area. MJ-1.day^{-1}) como descrito antes.

The morphological changes in plants resulting from the exposition to different radiation regimes imply in drastic changes in the relationship with the environment. In addition to the changes in leaf structure (SLA), the evaluated coffee plants presented great changes regarding their canopy architecture - rounding, opening, projection and volume - as well as the number of leaves, leaf density and leaf area index. These changes are presented and discussed in the previous work of this series (Measurement and Simulation of Light Availability Related to Growth of Coffee Plants in Agroforestry System with Rubber trees).

The understanding of the complex interactions between plants and environment as a whole has to be based on results obtained by several authors at different problem approaching scales. Thus, when gathering the various evidences found, one can apparently have a better understanding of the reality of the facts observed.

Phylotaxis - leaf distribution - of species adapted to shade conditions is usually organized as a planar series with branches next to the horizontal position (distichous phylotaxis on plagiotropic axes) (HALLÉ et al., 1978; LEIGH, 1975). This is the standard leaf arrangement in coffee plants. According to Givinish (1984), in such canopy architecture, with little overlapping of leaves, the increase of the transpirational costs due to the direct exposition to radiation in low luminosity environments would be nearly null. Thus, the low self-shading would have a great impact on the carbon balance, especially in environments with irradiance close to the compensation point.

Jarvis and Slatyer (1966) suggested that the resistance in intercellular spaces (r_i) might be a significant component of stomatal resistance (r_s) when the stomata are open. One can expect ri to be higher in thicker leaves than in thin ones and larger in leaves with small intercellular spaces than in those with larger spaces. An increased photosynthesis rate per leaf area unit would tend to increase the water use efficiency (WUE). An increase in the mesophyll cell surface/leaf surface ratio would certainly lead to higher WUE in that the photosynthesis would be more increased than transpiration (NOBEL, 1980).

Nutman (1937) was the first one to record the stomatal closing of coffee plants at full noon sun at as consistently dependent on the irradiance level under variable climatic conditions. Various authors have found higher values of stomatal opening in protected or self-shaded coffee plants and in cloudy or rainy days (NUTMAN, 1937; FRANCO, 1938; MAESTRI and VIEIRA, 1958; KUMAR and TIESZEN, 1980; FANJUL et al., 1985).

Givinish (1984) points that self-shading due to overlapped leaves would decrease the calorific load and transpiration costs in highly illuminated environments. Thus, the increase of leaf density in coffee plants at full sun in relationship with more shaded ones seems to act as a defense mechanism from high temperatures, as coffee plants are better adapted to environments with air temperature ranging from 18-22ºC. Nunes (1988) reported that temperature and vapor pressure deficit, and not irradiance, are the most important factors in stomatal regulation, provided that the irradiance level be above the critical value. Ludlow and Powles (1988) proved that shading can raise the hydric status and decrease leaf temperature in plants under hydric stress.

Sobral (2003), in an experiment similar to the one presented here, with assai plants (Eutherpe oleracea) in an AFS with rubber trees found that the difference in air temperature in relationship to the monocrop did not exceed 1ºC even in hotter hours of the day. Accordingly, changes in vapor pressure deficit had little difference in both environments.

Meinzer et al. (1990) observed that the highest WUE was a result from the reduction of the stomatal opening instead of increased photosynthesis, since the latter would be linearly correlated to the first one.

The results achieved - corroborated by the evidences found by several authors as discussed before - lead us to infer that the coffee plants close to the trees (under shade effect) in general had larger and thinner leaves, more open stomata due to higher hydric potential, however, with a lesser accumulation of dry matter due to the marking reduction of light availability. Differently, the behavior of monocropped coffee plants (full sun) was completely opposite, with smaller and thicker leaves, reduced opening stomata due to lesser hydric potential, presenting a higher accumulation of dry matter. Thus, the results achieved by dividing the transpiration by the leaf mass (Figures 3b and e), clearly show such factors acting in the system so that transpiration decreased as trees were more distant.

There does not seem to be any doubts on the direct correlation between the available irradiance fraction and the accumulated dry matter fraction (net photosynthesis) till its saturation as remarked by several authors (RUSSELL et al., 1989; ONG et al., 1996; BERNARDES, 1998; RIGHI, 2000). Since the transpiration per leaf mass occurred in the opposite manner, there is no other choice but confirm the higher WUE in full sun plant. More shaded plants had no reason for their stomata to act so as to restrict water loss, in view of the milder environment in which they were, therefore presenting a lesser WUE. Figures 3c and 3f, including the available radiation data, are elucidative in confirming such trend.

CONCLUSIONS

One concludes that expressing transpiration by leaf mass can be a means to access to the plant adaptation to the various environments, which is inaccessible when the approach is made by leaf area.

For experimental time period, coffee plants under shade showed higher water loss per unit of incident irradiance. On the other hand, plants in monocrop (full sun) performed a lesser water loss per unit of incident irradiance. Thus, the water use efficiency (WUE) of shaded coffee plants was demonstrated to be lower in comparison with monocropped plants.

FINAL CONSIDERATIONS

Plant evolution and firm land colonization were made possible by the stomata development, an efficient water loss controlling system.

Apparently, the water consumption in agricultural or natural systems can be higher in partially protected sites, as it is the case of AFSs in alley. As pointed by Kramer (1983), the goals of crop management are minimizing water loss through soil evaporation and maximum use by the crop. The soil cover by plant canopy would largely reduce water loss by evaporation. New studies are required in order to understand the extent to which less evapotranspiration-favorable micrometeorological conditions would be important in preserving soil water. In that sense, it would be important to quantify water loss by transpiration and evaporation separately instead of the usual evapotranspiration studies.

ACKNOWLEDGEMENT

Special thanks to the State Agency for Research of São Paulo/Brazil - FAPESP - for the support and to Prof. Dr. José Dias Costa for his unconditional help and ideas.

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