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Influence of shade management on gas exchange and transpiration of coffee plants (*Coffea arabica L.*)

Oliver Weidner[1], Reinhold Muschler[2], Heiner E.Goldbach[1] and Jürgen Burkhardt[1]

[1] Rheinische Friedrich-Wilhelms-Universität Bonn, Agrikulturchemisches Institut, Karlrobert-Kreiten-Straße 13, D 53115 Bonn, e-mail: j.burkhardt@uni-bonn.de or: h.goldbach@uni-bonn.de, Fax: #49(0)228732489,
[2] Centro Agronómico Tropicál de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica, CA, e-mail: muschler@catie.ac.cr

Abstract

The influence of permanent shading, exposure to full sun light, and cutting the shade tree on stomatal conductance, leaf temperature, and transpiration rate was investigated with coffee leaves. Those from shade adapted plants showed higher stomatal conductance compared to sun-exposed ones. Temperatures of top and canopy leaves where lower on shaded plants, whereas higher temperatures of exposed top leaves were found in the fully exposed ones. An impaired stomatal movement of the latter lead to peak temperatures up to 41° C. Stomata of coffee leaves still remained closed 10 days after pruning the shade tree. $\Delta^{13}C$ values differed between continuously shaded and unshaded plants and were lower after cutting the shade tree, too.

Keywords: Coffea arabica L., shade, photosynthesis, transpiration, leaf temperature

Introduction

Coffee production has increased considerably over the past decades by an enhanced use of inputs such as fertilisers and pesticides. One further factor for increasing the productivity of the tree is reducing or eliminating shade. This stimulates flower and fruit setting, but it may also pose a higher stress on the coffee plants (Muschler 1998), especially as even modern cultivars still show characteristic a low light saturation point typical for shade adapted plants, even when grown and adapted to high light intensities (Kumar and Tieszen 1980). An increase of light intensity far above light saturation may lead to photo-inhibition, especially when coinciding with further stresses such as water shortage (Nunes et al. 1993;

Ramalho et al. 1997). A lower stomatal conductivity of fully exposed coffee leaves has been found by Fanjul et al. (1985).
Premature decay phenomena have become increasingly important in intensive coffee production (Anonymous 1990a,b, 1992, Chaves 1992). In most cases, the premature decay has been attributed to a complex set of factors Anonymous 1992, Chaves 1992). Exposure to full sunlight may be one of several factors which contribute to premature decay phenomena in coffee plantations.

Aim of the study
The aim of our studies is to better understand the reaction of coffee plants to altered management practices, especially reduced shade or full exposure to sunlight.

Working hypothesis
It is hypothesised that a reduction of shade may lead to an altered hydric balance of the plant, multiple stresses by elevated leaf temperature and water losses and/or a reduced photosynthesis. The enhanced fruit set and this multiple stress may lead to a reduced carbon allocation to reserves in roots and stem tissue.

Material and Methods
Below, we present results of a first preliminary experiment set-up at the CATIE experimental station near Turrialba, Costa Rica (9°53'N, 83°38'E, 602 m a.s.l., 2650 mm annual rainfall, 994 mm ET_{pot}, average monthly R_{tot} 17,0 MJ·m^{-2}). The field in the experimental farm is part of an agroforestry experiment with *Erythrina poeppigiana* shade trees and *C. arabica* L., cv. Caturra. In our experiment, the influence of permanent shading, exposure to full sun light and a sudden change of shading by complete pruning the shade tree was investigated on the following parameters

i) Stomatal conductance
ii) Leaf temperature
iii) Transpiration rate of both, top leaves as well as self shaded leaves within the canopy of the coffee tree,

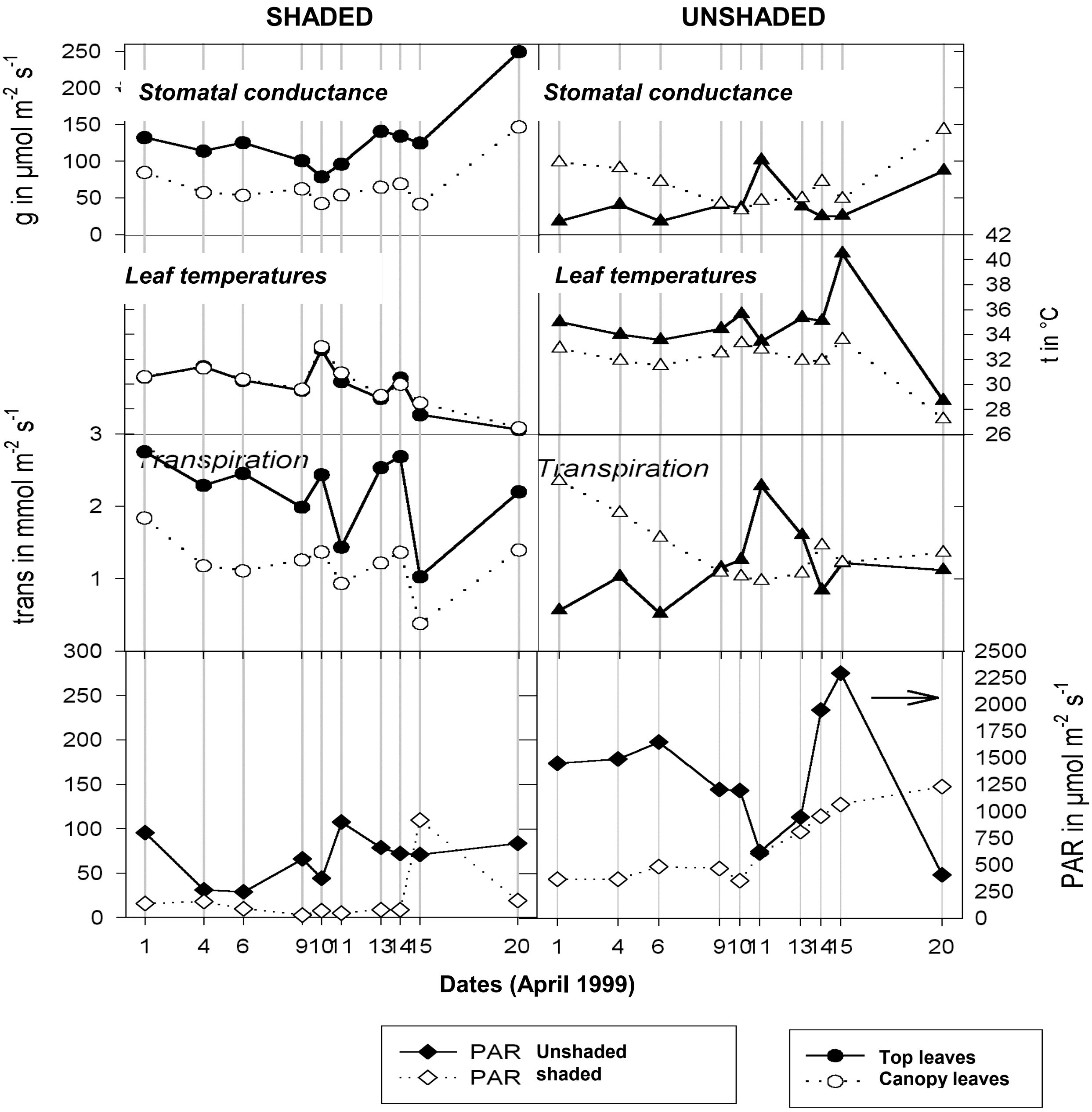
by using a LI-COR 1600 porometer. The measurements were done for a maximum of 20' per leaf to minimise cuvette effects on the stomatal opening.

Micrometeorological data were collected with a DELTA-T Logger Dl2e using the following sensors: PAR: SKYE, R.H. and air temperature: HMP45A , Vaisala, wind speed: A100R, 10' precipitation: ARG100 (both: Vector Instruments).

Carbon isotope discrimination($\Delta^{13}C$ *)*
For $\Delta^{13}C$ analysis, leaf samples (5 leaves, each) were collected of all treatments from 4 respectively 8 plants (others than used for the porometer measurements), dried at 70°C, finely ground and analysed with a Europa 20-20/ANCA element analyser

Results
It could be shown that leaves of shade adapted trees had higher stomatal conductances, especially of the top leaves, when compared to the sun-exposed plants. Leaf temperatures of top and canopy leaves where lower and almost the same for all leaves of shaded plants, whereas leaf temperatures were higher in the sun treatment, especially for the light exposed top leaves (Fig.1). Apparently due to an impaired stomatal movement, these leaves were not able to cope with increasing temperatures which peaked up to 41°C. Soil moisture was not considered as limiting under the experimental conditions, as Wrigley (1988) indicated that most of the coffee roots can be found between 30 and 90 cm, where no significant difference was observed in the water content by TDR. Water contents were only lower only in the top 30 cm of the unshaded area (22 *vs.* 33%, data not shown). Own observations, however, do not fully support Wrigley's view, especially for transplanted coffee which tends to possess a shallower root system. Nevertheless, amount and distribution of rainfall during the experimental period led us to assume that the soil water supply should not have been responsible for major differences in stomatal closure of unshaded plants.

Fig. 1: Comparison of stomatal conductance, leaf temperatures, transpiration rates, and PAR for top (=exposed) and inner (shaded) canopy leaves of *C.arabica* L., cv. Caturra as influenced by presence or absence of tree shade (*E. poeppigiana*); open symbols = inner canopy leaves, solid symbols = top leaves; data collected always at noon.



It could also be demonstrated that stomata of coffee leaves still remained closed 10 days after pruning of the shade tree (Fig.2). This, as well, lead to higher leaf temperatures (O.Weidner, unpublished). We were not yet able to observe whether photo-oxidative damage might have occurred in these leaves, but it was clearly to be seen that δ^{13}C values differed be-

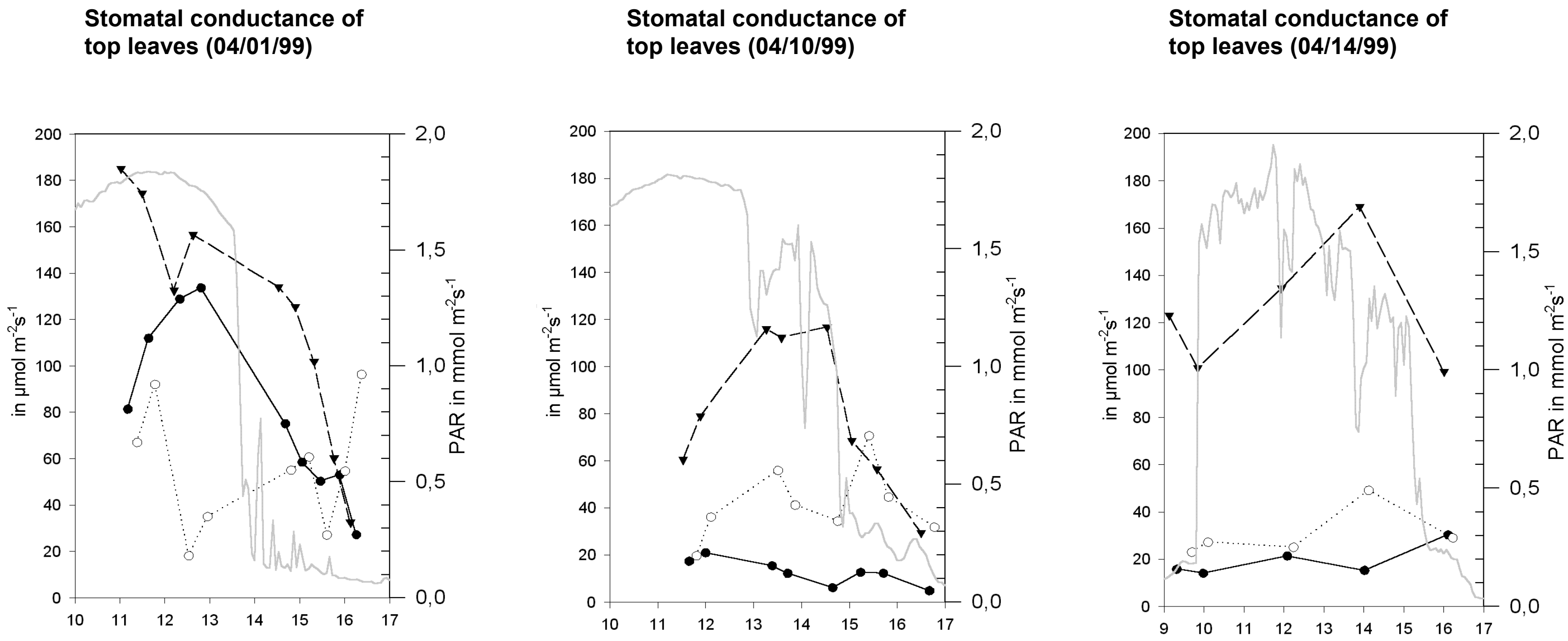


Fig. 2: Stomatal conductance of coffee leaves from always shaded (--V--) or unshaded (····o····) plants as compared to leaves where shade has been eliminated at 04/04/1999 (—o—); the grey solid line indicates the PAR at the leaf suface

tween shaded and unshaded plants and that lower values occurred also after cutting the shade tree (Tab. 1). These lower $\delta\ ^{13}C$ values could possibly be indicative for a significant stress in fully exposed leaves.

Tab.1.: $\delta^{13}C$ - values in leaves of coffee plants before (BC) and after (AC) cutting of the shade trees in comparison to shaded plants and fully sun exposed ones.

	Exposed leaves					
Treatment	BC	Variance	AC	Variance	Difference	Significance
shade	23,4	1,1	24,3	0,7	0,9	**
shadetree cut	23,4	1,1	21,1	0,5	-2,3	***
full exposure	20,5	0,6	20,5	0,5	0,0	ns
	Inner canopy leaves					
Treatment	BC	Variance	AC	Variance	Difference	Significance
shade	23,3	1,2	24,4	0,4	1,1	**
shadetree cut	23,3	1,2	23,3	0,6	0,0	ns
full exposure	22,2	1,0	22,8	1,3	0,6	ns

Discussion

Although the results are still preliminary, they show clearly that fully sun exposed coffee plants or plants after pruning respectively cutting the shade tree may suffer from temperature and water stress and exhibit a much lower photosynthetic rate. These data are in line with the few respective reports for coffee (Kumar and Tieszen, 1980, Nunes et al., 1968). Although coffee might adapt somewhat to high light conditions (about doubling of the light saturation point from 300 to 600 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ acc. to Kumar and Tieszen, 1980), much higher light intensities do occur in sun-grown plants (on an average 1400 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ in our experiments with peak values up to 2380 $\mu mol \cdot m^{-2} \cdot sec^{-1}$).

It is especially noticeable that heavy pruning of the shade tree led to a rather long-lasting closure of the stomata. It took over one week before they started to open again (at a rather low PAR of 625 $\mu mol \cdot m^{-2} \cdot sec^{-1}$, Weidner unpublished). Such a prolonged closure of the stomata can lead to an over-saturation of the photosystem and over time provoke photo-inhibition (Nunes et al. 1993, Matta 1997).

It is not yet completely understood why stomata of coffee leaves closed under full exposure to sunlight although soil water availability should have met the plant's demand. The most likely explanation is that the high temperature provokes a low local water potential in the leaves and thus stomatal closure. Kumar and Tieszen (1980) and Nunes et al. (1968) showed a significant reduction of photosynthesis at temperatures above 25°C which is likely caused by the same reason (plus a higher respiration rate). Although the lower PAR intensities in shaded coffee may not always allow the maximum photosynthetic rate, but there is much less risk for excessive temperatures, and temperature regulation by transpiration may keep the temperature of the leaves in an optimal range.

$\delta^{13}C$ seems to be a useful tool to determine the degree of light exposure of a coffee plant which is in agreement with other authors (Meinzer et al. 1989, 1991): lower values are found with increased shading. One has also to consider cultivar related differences of the carbon isotope discrimination (Meinzer et al. 1991). In contrast to Gutiérrez and Meinzer (1994), however, who found the highest photosynthetic activity related to the lowest $\delta^{13}C$ values, we observed an increased water and/or temperature stress coinciding with lower photosynthetic activities. Here, as well, we need further studies over a longer period to test the value of the parameter $\delta^{13}C$ for the quantification of (water) stress in coffee leaves.

Taken together with an enhanced fruit setting and further stresses, especially root damage due to nematode attack, growing coffee unshaded or with a very reduced shade may lead to a carbon starvation of the plants so that low carbon reserves permit only a weak re-growth after pruning the coffee, which is frequently observed with premature decay phenomena. These plants may also become more vulnerable to pathogen and pest attacks as well.

More comprehensive studies have to be undertaken to completely understand the influence of shade management on gas exchange in coffee plants and how shade management can be optimised for coffee under different ecological conditions. Management systems for coffee have to consider both, longevity of the coffee plant and coffee production. As replanting coffee is a severe financial burden, especially for small farmers, it should be kept at a minimum by enhancing the plant's longevity. An optimised shade management can result from a more detailed understanding of the behaviour of the coffee plant.

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