



Water loss by transpiration and soil evaporation in coffee shaded by *Tabebuia rosea* Bertol. and *Simarouba glauca* dc. compared to unshaded coffee in sub-optimal environmental conditions

M.P. Padovan^{a,b,c,*}, R.M. Brook^c, M. Barrios^b, J.B. Cruz-Castillo^d, S.J. Vilchez-Mendoza^b, A.N. Costa^a, B. Rapidel^{b,e}

^a Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (INCAPER), Afonso Sarlo, 160, Vitória, Espírito Santo, Brazil

^b The Tropical Agricultural Research and Higher Education Center (CATIE), 7170, Turrialba, Costa Rica

^c School of Environment, Natural Resources and Geography, College of Natural Sciences, Bangor University, Bangor, Gwynedd LL57 2UW, UK

^d Universidad Nacional Agraria (UNA), Managua, Nicaragua

^e CIRAD, UMR SYSTEM, 34060, Montpellier, France

ARTICLE INFO

Keywords:

Coffee agroforestry
Evapotranspiration
Coffee leaf water potential
Competition for water

ABSTRACT

There is increasing concern that due to land pressure and the need to maximize income, smallholder coffee farmers are increasingly being forced to cultivate in areas which are considered to be sub-optimal for coffee. Little is known about optimal coffee and tree combinations in these conditions and the degree to which crops and trees compete or are synergistic. In environmental conditions which were sub optimal for coffee cultivation in Nicaragua (1470 mm annual rainfall, 27 °C mean annual temperature and 455 m altitude compared to optima of 2000 mm, 23–24 °C and altitude between 1000 and 1400 m at that latitude, respectively), coffee and shade tree transpiration and soil evaporation were directly and separately measured in agroforestry (AFS) and full sun systems (FS). AFS was found to be a more efficient water user than FS because a greater proportion of rainfall was used by plant transpiration rather than being lost by soil evaporation. Plant transpiration accounted for 83% and 69% of evapotranspiration while soil evaporation represented 17% and 31%, in AFS and FS respectively. In AFS most of the water transpiration was due to coffee (72.5%) and much less by deciduous *Tabebuia rosea* (19%) and evergreen *Simarouba glauca* shade trees (8.5%). Furthermore, the study demonstrated the vastly different behaviour in water use by the shade trees. When in leaf, *Tabebuia rosea* transpired at four to six times the rate of evergreen *Simarouba glauca*, although crown sizes were similar. Contrasting precipitation between two consecutive years of study demonstrated that competition for water between coffee and shade tree occurred only in a severe dry season when coffee leaf water potential (LWP) reached its lowest values of −2.33 MPa in AFS. It was concluded that in most circumstances there was sufficient water for both coffee and trees, that coffee in AFS was a more efficient user of water than FS coffee, and that evergreen *Simarouba glauca* was more suitable as coffee shade tree compared to deciduous *Tabebuia rosea* in the sub optimal environmental condition studied.

1. Introduction

There are multiple challenges for coffee production. In Central America, as production expands, smallholder coffee farmers are increasingly being forced to cultivate in areas which are considered to be climatically and edaphically sub-optimal for coffee. Coffee production is also being threatened by increasing climate variability. For example, a recent study (Moat et al., 2017) reported that in Ethiopia, a major coffee growing nation, 39–59% of Arabica coffee growing areas could experience climatic change large enough to render them unsuitable for

coffee farming. Coffee shade has been suggested as a promising strategy to cope with the variability of available water and the increase in temperature in the context of global climate changes. Shade trees may buffer the effects of high temperature on coffee understorey (Barradas and Fanjul, 1986; Muschler, 1997; Partelli et al., 2014; Siles et al., 2009) and may increase water availability for plants use by reduction of soil erosion and runoff (Beer, 1995; Gomez-Delgado et al., 2010). On the other hand, shade trees may increase the whole system water use depending on the shade tree species, management, soil and environmental conditions. Competition for water between coffee and shade

* Corresponding author at: Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (INCAPER), Afonso Sarlo, 160, Vitória, Espírito Santo, Brazil.

E-mail addresses: mppadovan@hotmail.com.br, padovan@incaper.es.gov.br (M.P. Padovan).

tree is therefore, potentially one of the main disadvantages of coffee agroforestry (Bayala et al., 2015; Beer, 1987).

The assessment of competition or complementarity in water use in agroforestry systems (AFS) may be facilitated by evapotranspiration partitioning. Evapotranspiration comprises the processes by which water changes phase from a liquid to a gas: evaporation from the soil and transpiration through the stomata of plants (Kool et al., 2014; Wilcox et al., 2003). Transpiration is considered as a productive flux because it is related to plant growth while soil evaporation is regarded as being unproductive once it is lost to the atmosphere and is not used for plant biomass production (Liu et al., 2002).

Agroforestry systems may have a significant effect upon the soil evaporation component and thus water conservation. Evaporation from the soil is principally from the uppermost stratum where most fine roots are found (Padovan et al., 2015), thereby soil evaporation reduction may increase water retained in the soil and thus the overall proportion of rainfall used productively by crop and trees through transpiration (Zheng et al., 2015). Soil surface evaporation rates may be influenced by soil moisture (Liu et al., 2002; Wilson et al., 2000), as well as the thickness of litter layer (Villegas et al., 2010; Wei et al., 2015). In agroforestry, shade trees may reduce incident radiation and thus temperature of the soil surface with concomitant decrease of water loss by soil evaporation (Ilstedt, 2016) which may vary with the degree of canopy cover and trunk proximity (Wallace et al., 1999). In coffee agroforestry the effects of increasing shade tree density on the gradual reduction of soil evaporation was reported by Lin (2007). However, apart from this study no other soil evaporation measurements have been found in coffee agroforestry.

Transpiration, as the dominant component of evapotranspiration (Lawrence et al., 2006; Xu et al., 2008) has been assessed and compared in coffee in an agroforestry system (AFS) and unshaded full sun (FS) coffee in environments more suitable for coffee growing. Van Kanten and Vaast (2006) demonstrated that coffee transpiration was often greater in the full sun while the whole system water use was greater in the shade. Also, the variability of water use by the whole system was found to be dependent on shade tree species associated with coffee. Cannavo et al. (2011) showed that the higher water use by coffee and shade trees through transpiration plus water loss by interception resulted in lower drainage when compared to full sun coffee. However, despite water dynamics and use being significantly affected by shade trees little is known about water use of the whole coffee agroforestry system since most studies address one or another evapotranspiration component. Studies that integrate soil surface evaporation and plant transpiration in coffee agroforestry with appropriate techniques for both components are missing.

Here we studied the contribution of coffee and shade tree transpiration and soil evaporation to the total evapotranspiration in a coffee agroforestry system established in a sub-optimal environment by measuring each component directly. We also compared the water consumption by deciduous *Tabebuia rosea* and evergreen *Simarouba glauca* grown as coffee shade trees. Neither of these species have been studied in association with coffee. The results contribute to a better understanding of water allocation within the agroforestry system and coffee responses to moisture variability. This is important in order to identify shade trees ideotypes and possible management interventions which are more suitable for coffee agroforestry in the context of scarce water resources.

2. Materials and methods

2.1. Site description and experimental design

The study was carried out from February 2012 to April 2014 in an experiment located at Jardín Botánico, Masatepe, Department of Masaya, southern Nicaragua (11° 53' 54" N, 86° 08' 56" W) at a long term research site managed by the Centro Agronómico Tropical de

Investigación y Enseñanza (CATIE), jointly with the Universidad Nacional Agraria (UNA), Federación Cooperativas de Ahorro y Crédito (CENECOOP-FEDECARUNA) and Instituto Nicaraguense de Tecnología Agropecuaria (INTA). The experiment was established in 2000, as described by Hagggar et al. (2011).

Coffee growing by smallholder farmers in Nicaragua is extending into less favorable areas as farmers seek to enhance their livelihood options by growing cash crops, despite the sub-optimal edaphic and climatic conditions. The site is located in a coffee growing region, at 455 m a.s.l. which is considered to be rather a low altitude for arabica coffee (*Coffea arabica* L.) at this latitude, due to mean annual temperature being 27 °C which is high for *C. arabica*. Long term mean annual rainfall is 1470 mm, well below the optimum precipitation of 2000 mm. From 85% to 97% of the total annual precipitation falls over the wet season that lasts from May to November while a pronounced seasonal drought occurs from late November to mid-May (Vogel and Acuña Espinales, 1995).

Soils in the area are predominantly characterized as Andisols, derived from volcanic ejecta. These soils are typically deep, well drained and have high organic matter content, low bulk density, high allophane content and consequently a high phosphorus fixation capacity, high amorphous mineral content and high water retention capacity (FAO, 2001). On this particular study site, however, soils are characterized by the presence of an indurated layer locally known as *talpetate*. Such layers occur in about 15% of the Nicaragua Pacific region. Its properties reflect both geologic and soil-forming processes and can be extremely variable in nature (Vogel and Acuña Espinales, 1995).

The experimental design for this study had to be adapted to the layout of existing plots and consisted of a full sun monocrop coffee (FS) plot (1440 m²) and an adjacent coffee agroforestry system (AFS) plot (3200 m²), and is described in more detail in Padovan et al. (2015). Sub-plots for sampling were established within these main plots, as pseudo-replicates. In the coffee agroforestry system plot *Coffea arabica* L. (variety "Pacas", which is adapted to hot and dry environments) was associated with a mixture of *Simarouba glauca* DC. (Simaroubaceae) and *Tabebuia rosea* (Bertol.) (Bignoniaceae) planted as shade trees. Tree spacing was originally 4 m x 4 m, alternating both species (Hagggar et al., 2011), but tree density has been reduced over time by thinning to achieve a shade level appropriate for coffee production. The mean density of *Tabebuia rosea* was 113 trees ha⁻¹ and *Simarouba glauca* was 75 trees ha⁻¹ over the period of the study. Main characteristics of the shade tree species are presented on Table 1.

Coffee density throughout of the experiment was 4000 plants ha⁻¹, spacing being 2 m between rows and 1.25 m between plants in both the AFS and FS coffee. Coffee plants were pruned periodically in accordance with standard agronomic practice. Management includes fertilization with 37.3 kg ha⁻¹ of N, 48.8 kg ha⁻¹ of P and 27.6 kg ha⁻¹ of K as NPK compound fertilizer per year applied during the wet season in July and September. In addition 34.4 kg ha⁻¹ of N as urea and 12 kg ha⁻¹ of K as KCl are applied each year in November.

2.2. Climate

Two automatic weather stations were installed in the FS and AFS plots. Sensors installed at 2.50 m height were connected to dataloggers (CR1000, Campbell Scientific Inc.). Data were collected every 30 min from February 2012 to May 2014. Both weather stations measured relative humidity and temperature (HMP50, Campbell Scientific Inc.) and the FS plot weather station additionally measured solar radiation (CS300, Campbell Scientific Inc.), wind speed (03101, Campbell Scientific Inc.) and rainfall (TE525MM/TE525 M, Campbell Scientific Inc.). Reference evapotranspiration was calculated based on the FAO Penman-Monteith equation (Allen et al., 1998) using data from the automatic weather station installed in the FS plot.

Download English Version:

<https://daneshyari.com/en/article/6536872>

Download Persian Version:

<https://daneshyari.com/article/6536872>

[Daneshyari.com](https://daneshyari.com)