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Modifying micro-environmental growing conditions for the cacao tree by shade tree pruning

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Abstract

Cacao production systems are characterized by the occurrence of associated trees, the total stem density, the number of species, and the ecosystem services they provide. In a long term field trial in Alto Beni, Bolivia, comparing five cacao production systems, we monitored microclimatic differences at 1 m height between a cacao monoculture and two types of agroforestry systems with a fallow as a natural control. Cacao trees were spaced 4 by 4 m and associated trees were placed between the cacao rows in the agroforestry systems. Tree management included a regular cacao and shade tree pruning. We analyzed the effects of the main annual pruning on canopy openness, light and throughfall reduction, temperature fluctuations and vapor pressure deficits within the stand by comparing monocultures and agroforestry systems.

In agroforestry systems, trees reduced the radiation reaching the understory cacao tree due to their canopy cover, and intercepted precipitation. Under the agroforestry canopy it was cooler and the trees were less exposed to vapor pressure deficits.

The annual main pruning increased the canopy openness in an agroforestry system from 10 % to 31 %, photon flux density from 15 % to 63 % of total above canopy radiation and throughfall rate to the same level as in the monoculture while the stem density and tree species number of the agroforestry systems were maintained as before pruning. On the other hand, temperature fluctuations were not buffered anymore and vapor pressure deficit increased as high as in the monoculture.

Canopy openness decreased with increasing stem number. A high stem density and a closed canopy cover can cause light deficiency for the cacao tree, when radiation is reduced below the necessities for full photosynthesis. And that, in turn, affects productivity and yield. Pruning is an effective practice to manage the microclimatic conditions within the cacao production system without decreasing the number of stems in a stand. Especially under the viewpoint of climate change with increasing temperature and changes in precipitation patterns in cacao producing countries, agroforestry systems will provide less stressful conditions for the cacao tree and by pruning the light requirements can be managed. But the pruning intensity has to be adapted to local and seasonal climatic conditions to manage the ecosystem services of a shade tree canopy in favor of the cacao without losing its buffering function.

Introduction

Cacao production systems range from simple monocultures to complex agroforestry systems. Shade quantity and shade quality are important factors when discussing the potentials and limitations of agroforestry systems (Tscharntke et al., 2011). Full-sun monocultures are supposed to produce highest yields at least in the short term (Ahenkorah et al., 1974; Schneider et al., 2017), while agroforestry systems with fruit, timber and leguminous trees beside the cacao systems provide ecosystem services that come along with the species composition and shading intensity (Jacobi et al., 2014) and that may improve longevity of the plantation. Shade quantity is determined by the canopy structure. A monoculture with a dense cacao canopy already has a self-shading effect within the cacao leaves. In agroforestry systems, the associated trees built additional canopy layers above the cacao stratum that increase the total system shade up to a complete coverage of the soil. The microclimate in forests and agroforestry beneath the canopy is cooler and more humid compared to the surroundings (Beer et al., 1998; Martius et al., 2004). For cacao trees these conditions are favorable because high temperatures have a negative impact in yield (Daymond and Hadley, 2008) since cacao is sensitive to high levels of vapor pressure deficit (VPD) (Köhler et al., 2014). Agroforestry systems have higher system transpiration than stands with a lower stem density but shading also reduces the transpiration of the understory crop (Köhler et al., 2014). On the other hand, the humid conditions favor fungal pathogens (Schroth et al., 2000) and light might be limited even though cacao has a low light saturation compared to other crops (Baligar et al., 2008). Precipitation is intercepted by the canopy that is important for reducing the kinetic energy of rain drops from strong rainfall events (Gaitán et al., 2016) but reduces the water input into the soil in the dry season even further. Cacao farmers usually slash trees to reduce shading, while shade tree pruning is not very common due to a lack of knowledge, equipment and workforce (Andres et al., 2016). The other way round, pruning has the potential to modify light availability and regulate humidity to limit pathogens (Schroth et al., 2000), while maintaining biodiversity and associated ecosystem services (Tscharntke et al., 2011). We studied the direct effect of pruning on canopy openness and the associated effects on temperature fluctuation, VPD, throughfall and light transmittance, to enhance knowledge on shade tree management in agroforestry systems. Therefore, we compared the cacao tree pruning in a monoculture with the combined shade and cacao tree pruning in two agroforestry systems and with non-managed fallow plots without cacao in an experimental trial in Alto Beni, Bolivia.

Materials and methods

The study was conducted in Alto Beni at the foothill of the Bolivian Andes at 380 m a.s.l. with 1439 mm annual precipitation, 25.2 °C mean annual precipitation and 83% mean relative humidity (SENAMHI, 2015). The experimental site was established by the Research Institute of Organic Agriculture (FiBL) in 2008. All plots have size of 48 by 48 m. The cacao production systems comprise a cacao monoculture (MONO) with a stem density of 625 stems per hectare, an agroforestry system (AF) with a total of 1536 stems per hectare and a successional agroforestry system (SAFS) with 2431 stems per hectare (Niether et al., 2017). Various woody tree species as well as banana and plantain species are distributed in the agroforestry systems. The cacao trees and the shade trees were pruned at the end of the dry season between July and October. A non-managed fallow (BAR) was included in the trial to compare the cacao production systems with natural conditions. Further details on the systems and the management are given in Schneider et al. (2017).

All measurements were conducted before (July) and after (October) the annual pruning event in 2014 along a V-shaped transect in the center of the plots at 1.3 m height. Canopy openness (%) was estimated from hemispherical photographs (24 pictures per plot using a Nikon CoolPix5400 equipped with a FC-E8 converter lens with a 180° angle). The pictures (Fig. 1) were analyzed using Gap Light Analyzer (Frazer et al., 1999).

Photosynthetically active photon flux density (PPFD, µmol m^{-2} s^{-1}) was obtained at midday on cloudless days from photosynthetic active radiation (PAR) using an AccuPAR PAR/LAI-Ceptometer (LP-80, Decagon Devices, Inc., Pullman WA, USA). Transmitted light below the canopy was measured within the plots, while PAR above the canopy was measured outside the plots on five spots immediately before and after the corresponding within-plot measurements.

Total rainfall outside the plots and throughfall (mm) within the plots were measured with rain gauges (Ø = 17 cm). The throughfall rate was calculated from total rainfall and throughfall.

Dataloggers (Hobo Pro Series, Onset Computer Corporation, Bourne MA, USA) recorded temperature (°C) and relative humidity (%). The temperature fluctuations (°C) are defined as the amplitude between daily maximum and minimum temperature. VPD (kPa) was calculated from corresponding temperature and relative humidity.

We applied linear mixed-effect models using R (R Core Team, 2016) to describe the effects of *system*, *pruning* and the interaction (*system:pruning*) on the response variables, i.e., mean of in-field data of canopy openness, PPFD, throughfall rate, temperature fluctuation and VPD. *Block* was included as random factor. The significances of the effects were tested and when significant differences were observed post-hoc tests of pairwise comparison with differences of least significant means were applied (*lmerTest* R package, (Kuznetsova et al., 2016). When necessary, data were transformed to meet the normality and homoscedasticity of the residuals. Data are shown as mean ± standard error.

Results and discussions

Canopy openness was highest in the monoculture at the height of the cacao trees (Fig. 2a; Table 1) and even increased by the annual cacao crown formation pruning by 13 % (Fig. 1a, 1b). Before pruning, canopy openness was very low in the cacao production systems AF and SAFS and even lower than in the fallow BAR. Canopy openness increased by 21 % in AF (Fig. 1c, 1d) due to the strong shade and cacao tree pruning and by 7 % in SAFS (Fig. 1e, 1f), while the canopy was not managed in BAR. The shading was in the range of other studies on cacao agroforestry systems (Abou Rajab et al., 2016; Dietz et al., 2006; Schroth et al., 2016).

The light intensity within the stand (Fig. 2b) was related to the canopy openness of the systems (Siles et al., 2010a), but also relied on the total above stand radiation, that increased from the measurements before pruning (July: 1574 µmol m^{-2} s^{-1}) to the measurements after pruning (October: 2016 µmol m^{-2} s^{-1}). Transmitted light was low in the fallow BAR due to the high and dense canopy (Niether et al., submitted), and increased by 117 µmol m^{-2} s^{-1} from the measurements in July (pre) to those in October (post). This was a reference for the influence of the pruning beside the seasonal increase in transmitted radiation in the cacao production systems. Transmitted light increased by 561 µmol m^{-2} s^{-1} in MONO, by 623 µmol m^{-2} s^{-1} in MONO and 1030 µmol m^{-2} s^{-1} in AF, in accordance with the much higher canopy openness after pruning. While the cacao trees may have suffered from low light intensity for photosynthesis in AF before pruning (Baligar et al., 2008) the transmitted light was

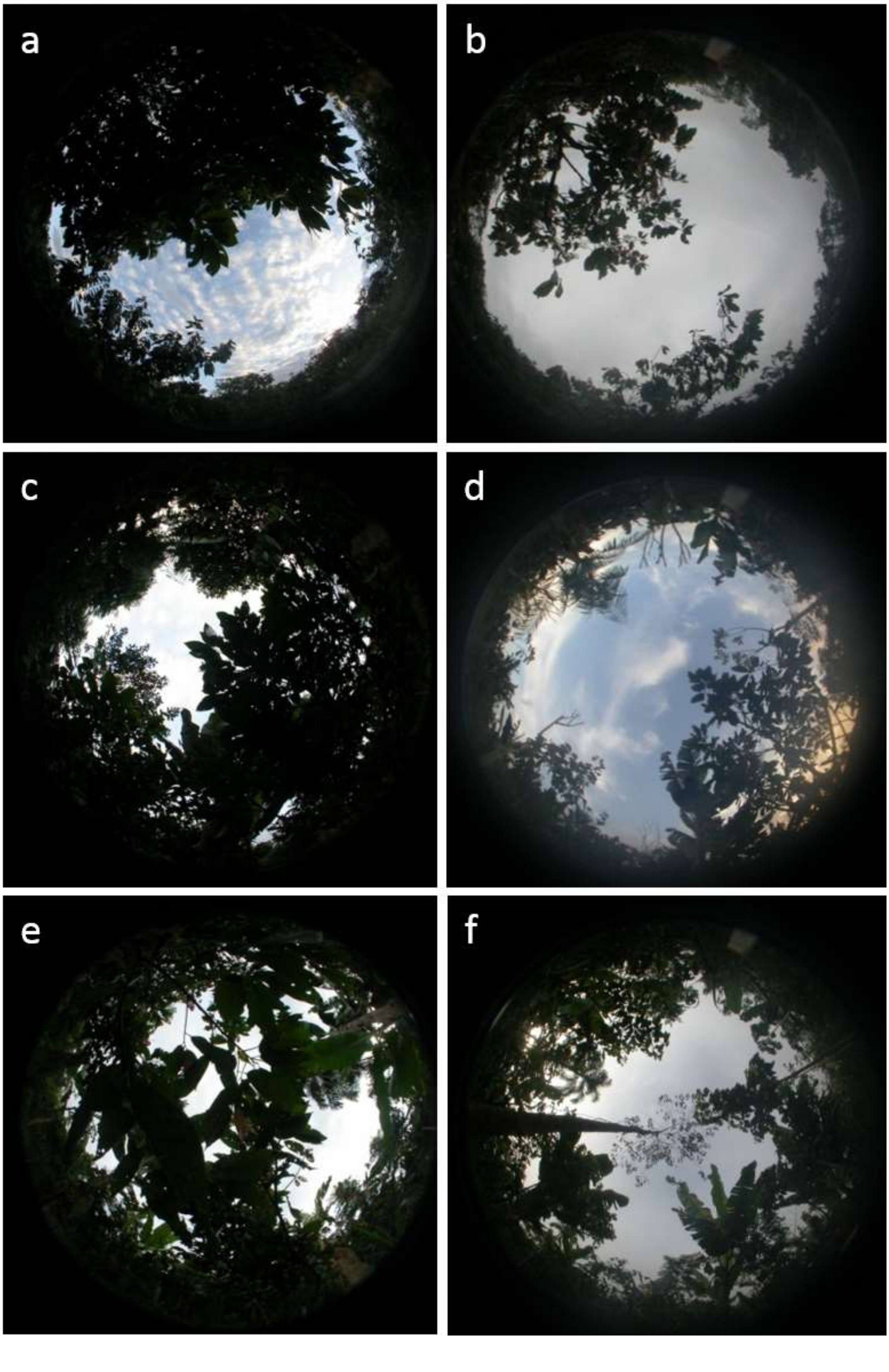

Fig. 1 Hemispherical photography in a cacao monoculture (a and b), an agroforestry system (c and d) and a successional agroforestry system (e and f) before (left) and after (right) pruning.

The throughfall rate depends on the canopy openness, but also on the total precipitation and rainfall intensity (Crockford and Richardson, 2000). July was the month with the lowest total precipitation that increased within the following months in the transition from the dry to the rainy season (Niether et al., submitted). In BAR, the throughfall rate decreased slightly from July to October (12 %), but was high as in MONO, where the throughfall rate did not change despite the cacao tree pruning (Fig. 2c). Instead, the throughfall rate increased in AF after pruning by 30 %. While the throughfall rate was significantly lower in AF and SAFS before pruning, no difference was observed any more between the cacao production systems after pruning (Niether et al., submitted). Despite the very dense canopy of the fallow BAR with low light transmittance, the throughfall rate was high all the time and at the same level as the cacao monoculture, that must be related to the species canopy characteristics (Niether et al., submitted): the dominant trees in the fallow BAR were pioneer species of the genus *Cecropia*, fast growing tree species that invest more in height than in strength (Sposito and Santos, 2001) and built up a dense, but thin crown with a corresponding low water storage capacity and interception rate (Crockford and Richardson, 2000).

Like the light intensity, temperature and humidity increased from July to October in the course if the season from winter to spring. Accordingly, also the temperature fluctuations (Fig. 2d) and the VPD (Fig. 2e) increased in all the systems independently from pruning. In BAR with the dense canopy, temperature fluctuations were lowest from all systems and increased by 3.6 °C without pruning. In AF and SAFS, temperature fluctuations were low like in BAR before pruning and increased by 7.9 °C in AF and 6.5 in SAFS. 4.3 °C increase of temperature fluctuations were observed in MONO. The same was observed for the VPD which increase by 0.59 kPa in BAR, while it increased by 0.70 kPa in MONO, 0.81 kPa in AF and 0.7 in SAFS. After pruning, the temperature fluctuations and VPD were at the same level in MONO, AF and SAFS, while it maintained much lower in BAR, implying higher need for transpiration of the cacao tree (Lin, 2010).

Strong pruning decoupled the buffer function of the agroforestry systems for high temperatures and climate extremes (Niether et al., submitted) and increases the ecophysiological stress for the cacao tree (Beer et al., 1998). But insufficient tree management and pruning may increase the humidity in the systems and thereby the incidence of pests and limits the photosynthesis and finally the yield (Armengot et al., 2016).

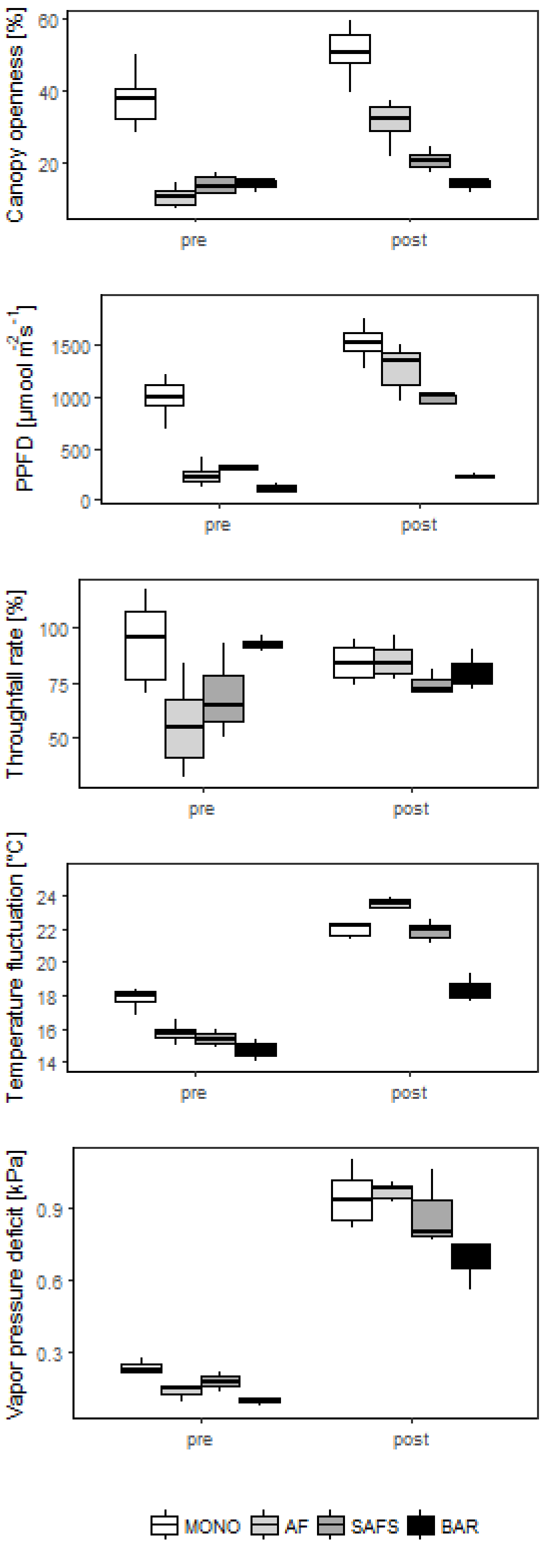

Fig. 2 Pruning effects. Canopy openness and microclimatic parameters before (pre) and after (post) pruning in cacao monoculture (MONO), agroforestry system (AF), successional agroforestry system (SAFS) and fallow (BAR). PPFD: photosynthetically active photon flux density.

Table 1 Results from linear mixed-effect models. F-value and level of significance (* for p < 0.001; ** for p < 0.01; * for p < 0.05) of the fixed factors *system* (MONO, AF, SAFS, BAR), *pruning* (before and after) and their interaction *system:pruning*. PPFD: photosynthetically active photon flux density (adapted from Niether et al., submitted).**

	system		*pruning*		*system:pruning*	
canopy openness	212.8	***	124.8	***	10.2	***

PPFD	129.3	***	224.1	***	23.3	***
throughfall	4.3	*	0.4		4.7	**
temperature fluctuations	396.7	***	22.4	***	13.4	***
vapor pressure deficit	1005.2	***	6.2	**	4.6	*

Conclusions

Shade and cacao tree pruning increased the incoming light and water input by throughfall while maintaining the high diversity of an agroforestry system. The understory cacao trees were benefited from higher light intensity and from additional water supply at the end of the dry season. On the other hand, pruning reduced the buffering function of the shade canopy and within a short time, the cacao trees were exposed to high temperature fluctuations and VPD that implies a transpiration of the cacao tree. Pruning is an effective tool to manage agroforestry systems, but pruning intensity and timing has to be adapted to the locality and the season to prepare conditions in favor of the cacao.

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