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Microclimate Effects on Flowering Success in Coffee Agroforestry Systems

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Abstract: The microclimatic factors that effect flowering success in coffee agroecosystems (Café arabica) are not well understood. While some studies show that high soil moisture and high light levels are necessary to promote floral formation, other studies have found that low ambient temperatures are most influential. However, the individual microclimate findings are conflicted in the context of shaded coffee agroforestry systems where there is a tradeoff between high light and low temperature or high soil moisture. This study examines the role of light, soil moisture, and temperature on coffee flowering in agroforestry systems with high (60-80%), medium (30-50%), and low (10-30%) shade cover. Flower development was positively correlated to shade cover, with the high shade site producing significantly more flowers. Linear Mixed Model analysis (LMM) showed that light and soil moisture explained a significant amount of variation in flower number where sites with low light and high soil moisture produced more flowers. Still, data showed that severe light limitation due to self-shading could reduce flower development within low branches and innermost branch nodes. These data suggest that shade cover in agroforestry coffee systems are important for floral formation because of the effect shade cover has on microclimate.

Key words: Coffee · anthesis · agroforestry systems · shade effects · microclimate

INTRODUCTION

In Southern Mexico, coffee (*Coffea arabica* L.) phenology is greatly controlled by the precipitation patterns of the region. For example, it has been noted that flowering occurs only after a distinct period of drought [1,2]. Blossoms are then triggered by the onset of occasional spring rains [10] and if flower buds are water stressed at this period of development, flowers will develop abnormally into star flowers, reducing final production [3]. Therefore, flowering patterns depend greatly on both the water stress induced by the dry season as well as the subsequent spring rains that occur at the end of the dry season.

Research on the effect of temperature for coffee flower development has found advantages to lower ambient temperatures [4]. Drinnan and Menzel [5] showed that more floral buds were developed at lower temperatures (23/13°C) than at higher temperatures (33/23°C). Camargo [6] found that relatively high temperatures during blossoming may cause flowers to abort, especially when associated with prolonged dry periods. Mes [7] found that at higher day temperatures (30°C) axillary buds remained undifferentiated and plants sustaining longer periods at this day temperature formed many star flowers. This results in a decrease in viable flowers [8], lessening coffee production.

Other highly influential reports in coffee agriculture have suggested that coffee flowering is controlled primarily by the amount of light reaching coffee trees, with more sunlight resulting in more flowers [9-11] possibly because more nodes are formed per branch or more flower buds exist at each node [12,13]. This information has encouraged many farmers to remove shade tree cover in order to increase coffee yields by increasing flower production [14] and as an important side note, this reduction of shade has caused a large scale loss of habitat for many animal species [15]. Yet, recent literature has pointed out that the results of the light effect have not been thoroughly documented [16] and should be further investigated before recommendations are made regarding the reduction or elimination of shade trees in coffee farms.

Based on the above knowledge, one would expect that farms with increased light penetration, such as less shaded systems, would have a higher number of flowers. Yet, the lower temperatures in more shaded systems [9,17]

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should lead to increased flower production as well [5]. Due to the opposing nature of these triggers and their related shade coverage, it is difficult to predict if the reduction of shade due to management intensification will result in higher or lower flower production. The question then is to understand where the optimal point of flower development is within the variation of shade regimes for coffee agroecosystems. More research is required to understand the effect of such interacting factors on flowering.

Because previous studies have focused solely on one microclimate factor at a time, a thorough understanding of the intricate relationship of microclimate and flower development is still lacking. For these reasons, a study was conducted to examine the effect of light, soil moisture and temperature on flower number in coffee farms of Southern Mexico. Information that leads to a greater understanding of optimal shade level for coffee flowering will be advantageous to coffee producers, especially in establishing best management practices and designing coffee production systems.

MATERIALS AND METHODS

Site Description: Two large coffee farms in the Soconusco Region of Chiapas, Mexico were chosen with close geographic proximity in mind to ensure similar site and climate conditions, such as solar radiation, precipitation and wind effects. Finca Irlanda is located at (15°11'N, 92°20'W) and Finca Hamburgo is located at (15°10'N, 92°19'W). Both farms are situated approximately 40 Km NE of Tapachula, Chiapas, Mexico. The farms are composed of a layer of coffee shrubs in the understory with single or multiple layers of shade canopy in the overstory. The coffee shrubs are planted along the hillside in rows (1.5m x 2m).

Finca Irlanda is separated into two sites because part of the farm is considered a traditional polyculture, as described by Moguel and Toledo [18], with some original shade trees as well as planted shade trees to create multiple canopy layers. The remainder of the farm is a commercial polyculture with fewer shade trees and canopy layers. Here we classify the traditional polyculture site as a High Shade (HS) site with 60-80% shade cover and the commercial polyculture site as a Medium Shade (MS) site with 30-50% shade cover. Finca Hamburgo is a shaded monoculture and thus we classify it as a Low Shade (LS) site with 10-30% shade cover. Shade cover was estimated in each plot using densitometer measurements (Geographic Resource Solutions, Arcata, CA) two times during the flowering period in order to take into account changes in shade level. These sites will be referred to from this point on by their shade level designation: High Shade (HS), Medium Shade (MS) and Low Shade (LS).

Six 5m x 5m contiguous plots were established on each site from July 2004 to November 2005. The plots were placed 10 meters apart in a row along two rows of coffee in order to limit variability among the plots. All sites had an eastward facing aspect with a slope of 30 to 40 degrees and were located 950-1000 meters above sea level. Light quality in each plot was measured with a GOSSEN Luna Pro Digital Incident and Reflected Light meter (Gossen Foto and Lichtmesstechnik GmbH, Nurnburg, Germany)

Three weather stations (Davis Instrument, Heyward, CA) were placed on each site within the area of the six plots from July 2004 to November 2005, but data from this study are from the flowering months in this region, December 2004 to March 2005. The weather stations recorded data on temperature, humidity, rainfall, wind speed/direction and solar radiation and data were averaged and recorded every two hours. Soil moisture measurements were taken and data logged using soil moisture probes (using electrical resistance) (Davis Instruments, Heyward, CA). Twenty-four soil moisture probes were placed in each farm with four sensors on each plot. The soil moisture probes averaged and recorded moisture measurements (in centibars of tension) every two hours, leading to twelve total measurements per day.

Flower Counts: Two coffee trees were chosen in each plot, for a total of twelve trees per site. Four branches were marked in each tree. The branches were chosen so that each branch pointed toward a different cardinal direction: north, south, east and west, in order to obtain a random selection of branches stratified by direction. The branches were also chosen so that there was at least one branch at each height level of the tree: high, middle and low. This was done in order to get a random selection of branches stratified by height of the tree [19]. The fourth branch was randomly chosen from one of the height categories.

There were three rainfall events during the dry season, from December 2004 to March 2005. Anthesis occurred approximately two to three weeks after each rainfall event. After each flowering period, the number of flowers that opened on the last five nodes of each of the selected branches was counted and recorded. Nodes were numbered one to five with node one being the outermost node that flowered and node five being the innermost node of the counted set of nodes. A total flower number was calculated for each node of each branch.

Linear Mixed Model Analysis: A Linear Mixed Model (LMM) was used to analyze differences in flower totals among the sites because the data were hierarchical and clustered and observations were collected repeatedly over the course of three months on the same plots, trees, branches and nodes within each site [20]. The data sets were analyzed in SPSS v.13.0 (SPSS, Chicago, IL). The analyses examined the relationship of flower total to light, soil moisture and temperature, which may have been correlated to measures. In the analysis, the assumptions of normality and constant variance in the random errors were assessed with standard diagnostic tools. The proportion of the variance in the measurements due to random plot, tree, branch and node effects were estimated using random intercepts associated with the plots, trees, branches and nodes in the LMM [20].

Fixed effects were analyzed in order to compare means of measures. The LMM included fixed effects associated with site, light, soil moisture and temperature as continuous covariates to assess continuous trends in flower number as a function of date. The LMM also included random effects associated with the randomly selected plots nested in site, trees nested in plot, branches nested in trees and nodes nested in branches to capture within correlation of the measures.

RESULTS

Site level data showed that the HS site produced the highest number of flowers with 2132 flowers. The MS site had 1893 flowers and the LS site had 1181 flowers. Light, soil moisture and temperature showed good correlations with flower totals when flower totals were averaged by tree for each site (Fig. 1).

Results of flower totals from the LMM showed that the sites were significantly different (df=9.58, F=8.33, p=0.008) with the LS site significantly lower than the HS and MS sites (Fig. 2). Light explained a significant amount of variation (df=527.18, F=28.35, p<0.0001), soil moisture was marginally significant (p=0.073) and temperature was not significant (p=0.816) (Table 1). Light was negatively correlated to flower production, while soil moisture was positively correlated to flower production (Fig. 1).

At the branch level, total flower number per branch was found to be statistically significant (ANOVA, p<0.0001), with high and middle branches having significantly more flowers than the low branches. Analysis of branches that faced different cardinal directions showed no significant difference. On the node

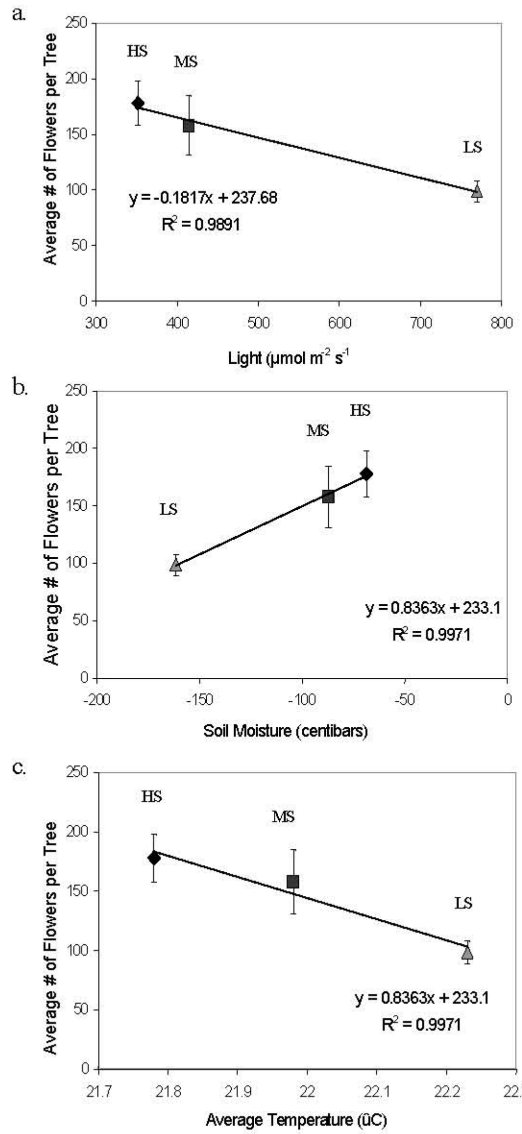

Fig. 1: Trends of Light (a) Soil Moisture (b) and Temperatures (c) based on shade cover of site. Standard error bars were calculated for each site

Table 1: Linear Mixed Model Results: Table of degrees of freedom (*df*), F values (*F*), P values (*P*) and Estimated Variance Components for Flower totals during the 2005 season. Random Factor Intercepts are given for each model

Sources of variation	df	F	P	Estimated variance components
Site	9.58	8.33	0.008	
Light	527.18	28.35	<0.0001	
Soil moisture	135.49	3.27	0.073	
Temperature	13.27	0.056	0.816	
Random factor Intercepts				
Plot (site)			0.099	4.26
Tree (plot)			0.19	2.59
Branch (tree)			0.132	1.83
Node (branch)			0.084	1.01

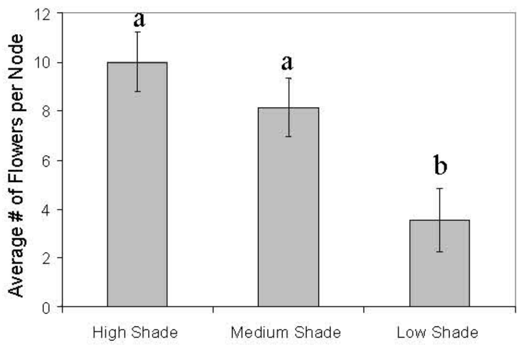

Fig. 2: Average number of flowers per node by shade cover: Site averages taken from LMM analysis. Standard error bars were calculated for each site (a and b groups are significantly different at p=0.05 level)

level, the number of flowers developed per position of the node was significantly different (ANOVA $p<0.0001$), with node five developing significantly less flowers than nodes one through four.

DISCUSSION

The results of this study suggest that both light and soil moisture have a large influence on the development of flowers on coffee trees. Temperature may also have an effect, but ambient temperatures never exceeded the 30°C threshold stated in the other literature [17]. The number of flowers that developed is significantly different among the sites, with the LS site developing significantly fewer flowers than the HS and MS sites (Figure 2). This is contrary to the current assumption that less shade with greater levels of light would have greater flower production. This may be because the increased light levels in the LS site created environmental factors that negatively affected flowering, therefore causing a decrease in flowering. The flower data suggests that more highly shaded farms, which receive less light to the understory, are still able to produce many flowers, perhaps due to the increased level of the soil moisture in the site, as suggested in previous literature [3]. Therefore, on the site level, decreased soil moisture in the LS site may have a negative effect on flower development, offsetting the positive effect of increased light levels.

The original studies on the effect of light on flowering are therefore not supported by this study. Perhaps in sites where soil moisture is not limiting, high light will result in greater floral formation, but in water-limited systems, soil moisture becomes a more important factor toward determining floral success. Too little light in water stressed systems will still result in lower floral formation though. Branch height data showed that the low branches on average produced fewer flowers than the high and medium height branches. The node position results showed that the innermost node produced significantly fewer flowers than the four outermost nodes. Both results may be due to self-shading since lower branches and inner nodes naturally receive less light [21].

In conclusion, although a minimum of light is necessary for flower development, there is a need to look at the overall environmental health of the system to determine flowering success. If other environmental factors are not ideal for growth, increased light penetration will not increase flowering potential. This suggests that the trade off of light versus soil moisture is quite high in this region, where greater flower development is dependent on environmental variables that come with increased shade cover. Therefore farmers in water-limited systems may find that increased shade in agroforestry systems can actually provide a suitable environment for flower development and production.

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