Coffee Shade Tree Management: An Adaptation Option for Climate Change Impact for Small Scale Coffee Growers in South-West Ethiopia

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1 Introduction

Coffee (*Coffea arabica* L.) is one of the most important cash crops that have been contributing a lion's share to Ethiopia's economy. It is a crop that is grown within a large variation of shade cover (Lin 2007). It varies from traditional forest coffee (i.e. rustic coffee), which is planted under a forest canopy to intensive coffee agriculture, which has little or no shade cover. In Ethiopia, coffee is generally grown under four types of production systems, namely: forest, semi-forest, garden and plantation coffee (Weldetsadik and Kebede 2000; CFC 2004). The major coffee production system in the highland of south-western Ethiopia is referred to as 'semi-forest coffee' (Labouisse et al. 2008); although in many of the forest, wild coffee (forest coffee) is still found sparsely scattered in remote parts of the forest (Samnegard et al. 2014). The semi-forest coffee is grown in the understory of natural moist afro-montane forests with low annual management. Such areas are widespread in the margin of the large contiguous forests. Coffee is also grown isolated from the contiguous forests in forest patches surrounded by an open agricultural matrix of

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open crops and shaded by trees (Gove et al. 2008; Samnegard et al. 2014). Because of forest fragmentation, such a setting is typical in coffee producing areas of southwestern Ethiopia.

The exposure of forest environment to external climatic conditions, due to forest fragmentation and the creation of forest edges, could reduce the ability of a forest to buffer its internal microclimate from more extreme macroclimate conditions (Ewers and Banks-Leite 2013). The microclimate could differ, between coffee grown under shade in the margin of the large contiguous forests and small forest patches surrounded by an open agricultural matrix of open crops. It could be assumed that such a contrast could both directly or indirectly affect the internal microclimate condition of each coffee plot. The land-cover change provides an additional major factor that alters climate, through changes in the physical properties of the land surface (Pielke et al. 2002). The land use/cover types surrounding the coffee plots might have an impact on the internal microclimate variability of each coffee agro-ecosystem. As in agricultural landscapes, trees and shrubs occur on farms in different spatial and temporal arrangements with crops and outside farms in communal lands.

Depending on the quality of the surrounding matrix, it can be expected that these processes of fragmentation has caused significant changes on microclimate of fragmented coffee plots. Moreover, the contrast between coffee grown under shade and in the open in terms of microclimate variability were not done extensively in Ethiopia. Therefore, the objectives of this study were to characterize the influence of the land use/cover types on the internal microclimate of coffee plots and compare the microclimate variability under shade and in the open in south-west Ethiopia.

2 Materials and Methods

2.1 Description of the Study Site

The experiment was carried out in Ethiopia, Oromia Regional State, Jimma Zone, Ageyo-Setema research site (08°03″96′–08°04″19′N, 36°32″84′–36°47″04′E; altitudes ranging from 1505 to 2124 m above sea level) from June 2012 to 2015 (Table 1). The coffee plots were selected from two districts/woredas of Jimma Zone: Gumay and Setema (Fig. 1). It is located around 100 km in the northwest of Jimma town. The local rainfall pattern of the study site is nearly mono-modal, with a main rainy season from June to August, inducing a single coffee crop harvest season from October to December. The topography of the area is undulating landscape that consist of a mosaic of crop land, pasture, forest fragments managed for coffee production and isolated farmsteads, and patches of exotic timber tree species.

Table 1 Mean daily temperature, relative humidity and wetness duration among the different coffee classes during wet season at Ageyo-Setema study site in 2012 and 2013

Coffee class	Year					
	2012			2013		
	Temperature (°C)	Relative humidity (%)	Wetness duration (h/day)	Temperature (°C)	Relative humidity (%)	Wetness duration (h/day)
1	17.73^{a}	89.90^{c}	0.15^{c}	17.78^{a}	89.74^{c}	0.21^{c}
2	16.97^{b}	90.81^{b}	0.18^{b}	16.84^{b}	91.23^{b}	0.25^{b}
3	16.52^{c}	92.53^{a}	0.23^{a}	16.58^{c}	92.89^{a}	0.27^{a}

Means sharing the same letter in the column do not differ significantly at 5% probability level using HSD test

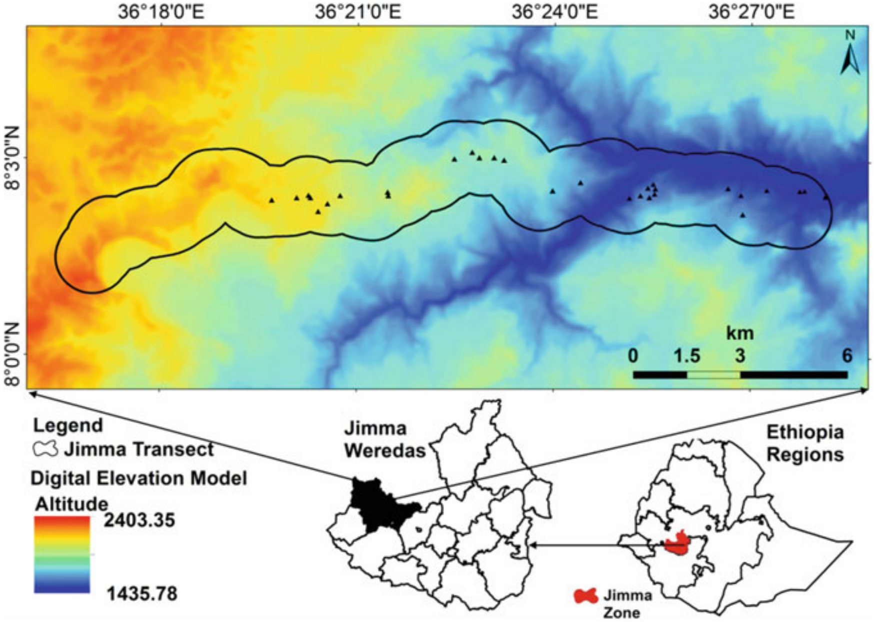

Fig. 1 Map of the study area: Ageyo-Setema research site (*triangle shaped dots* represent coffee plots of the present investigation)

2.2 *Experimental Plot Selection*

A total of 30 coffee plots of 20 m × 20 m, smallholder coffee farms were selected along Ageyo-Setema altitudinal transect (Fig. 1). The plots were selected along the transect considering the level of fragmentation. The coffee produced in the study area is exclusively *Coffea arabica* and the coffee trees used for the study were more than 25 years old local landraces (variety). Coffee field management namely slashing of the understory shrubs and weeding is done once or twice per year, one or two weeks before harvesting the berries. Farmers do not fertilize nor apply any other chemical input on their coffee farms. The dominant shade trees used in the selected coffee plots are *Albizia gummifera, Cordia africana, Millettia ferruginea, Croton macrostachyus, Acacia abyssinica, Ficus vasta, Ehretia cymosa, Dracaena steudneri* and *Vernonia amygdalina.*

2.3 Data Collection

2.3.1 Land Use Land Cover

The Land Use Land Cover (LULC) of the Ageyo-Setema transect were identified from aerial and satellite images as described by Hailu et al. (2014). The classification was Object Based Image Analysis (OBIA) that produces eight classes. These classes were Closed Herbaceous Vegetation (pasture), Indigenous Forest, Small Sized Field of Graminoid Crop(s), River, Roads, Extraction Sites, Urban Area, and Exotic Forest (Hailu et al. 2014). After the classification and digitization, the LULC (at 2 m × 2 m resolution) of the transect was clipped with 50, 100 and 200 m radius of each coffee plots to know the LULC types around each coffee plot. Hence, a total of 24 descriptors (LULC variables) per plot were generated (eight LULC at three radius around each coffee plot) for characterization of the plot.

2.3.2 Microclimate Data

Data loggers, that is, Maxim iButton, were installed in each coffee plot from June 2012 to 2014 to record the temperature (°C) and relative humidity (%) every hour with specified accuracy of ±0.05 °C and 0.0625% resolutions, both in coffee plots and in the open areas. But wetness duration (h) was calculated from relative humidity; a value recorded when relative humidity become 100%. The loggers were hung on coffee trees at the center of each coffee plot and single tree in the open on average at 2 m above the ground and protected from direct sun. The collected data were downloaded from data loggers to a laptop computer using a cable on average at two months interval. The hourly collected temperature and relative humidity data were aggregated on daily, monthly and season basis during the analysis.

2.4 Statistical Analysis

The clipped eight LULC variables generated at each scale was used for characterization of the 30 coffee plots based on the number of pixels they generated around each coffee plot. Preliminary analysis was done on the 24 LULC variables generated before using all the descriptors for further analysis. After preliminary analysis road, urban, extraction site and river variables were found to be less contributors to the variation at all the scales considered and were excluded from further analysis.

Indigenous trees, exotic trees, crop land and pasture land were only used to understand the strategies of farmers in using open land. To avoid multi-colinearity problem between these LULC variables, Principal Component Analysis (PCA) was run at each scale separately. This step was important to identify whether there was correlation between the four selected LULC variables or not to use them for further analysis. In all the scale considered, crop and pasture land were negatively correlated to indigenous and exotic trees respectively; and were then excluded from the analysis while explaining the relationship between LULC with microclimate of the transect as well as each coffee plots along the altitudinal gradient (see result part).

On the other hand, indigenous and exotic trees were independent to each other at each scale; and were used for further analysis. Consequently, total trees (indigenous + exotic trees) were added together at each scale (T50, T100 and T200). However, T50, T100 and T200 were highly correlated to each other. Using these three variables, PCA was further run to construct two independent synthetic variables (Trees1 and Trees2) by considering the first two principal components (PC). Trees1 and Trees2 were created depending on the two axis (PC). Trees1 represent the global tree canopy density around each plot (more contribution from T100) while trees2 represents the tree canopy density close to the plot (contributed more by T50) and at the periphery of the plot (contributed more by T200). Then, hierarchal cluster analysis based on “mcquitty” method was employed to classify the 30 coffee plots into different groups using Trees1 and Trees2 variables. The number of clusters was determined by running Multivariate Analysis of Variance (MANOVA) test as well as our personal observation of the actual coffee plots used for the study.

To determine the variation of microclimate among different coffee classes particularly during wet and dry season, daily mean, minimum and maximum temperature (°C) and relative humidity (%) was calculated from logger data over two years; 2012 and 2013 for wet season (June to August) and 2013 and 2014 for dry season (February to April). Daily sum of wetness duration was calculated by summing up the total wetness duration over the specified period and divided by 24 h to get daily sum of the wetness over the transect. For the wet season, data were collected and summarized over 70 consecutive days from June 22 to August 30 in 2012 and over 91 consecutive days from first of June to August 30 in 2013. For the dry season, data were compiled over 85 consecutive days from February 5 to April 30 of 2013 and 2014. These specific months were selected because they represent the wet and dry season. January was not included in the dry season because of non availability of the data. Furthermore, the temperature under shade and open area was also compared.

Finally, analysis of variance (ANOVA) was run to test whether there was significant difference between the different classes of coffee plots with respect to daily mean temperature and relative humidity for both seasons and years separately. Tukey’s ‘Honestly Significant Difference’ (HSD) method was calculated and used to identify significantly different means. All statistical analysis was performed using R software version 2.15.1 (R Development Core Team 2012).

3 Results

3.1 Characterization of Coffee Plots Using LULC

The clipped LULC analysis indicated that the coffee plots have a great variety of LULC in their surrounding areas (Fig. 2). It includes the proportions of area covered with trees (both exotic and indigenous), crop lands, pasture lands, urban, roads and river areas. Some of the plots are composed of small areas of trees and large areas of cropland. For example, plot 20 has 177 pixels of trees, which encompasses 1106.25 m^2 area and 4848 pixels of cropland, which is 30,300 m^2 areas at 100 m scale (Fig. 2). On the other hand, some plots have large areas of trees and small areas of cropland. For example, plot 13 has 4230 pixels of trees (26,437 m^2 area), 525 pixels of cropland (3281 m^2 area) and 265 pixels of pasture (1656 m^2 area). In addition, there are plots with almost equal proportion of cropland and trees. For

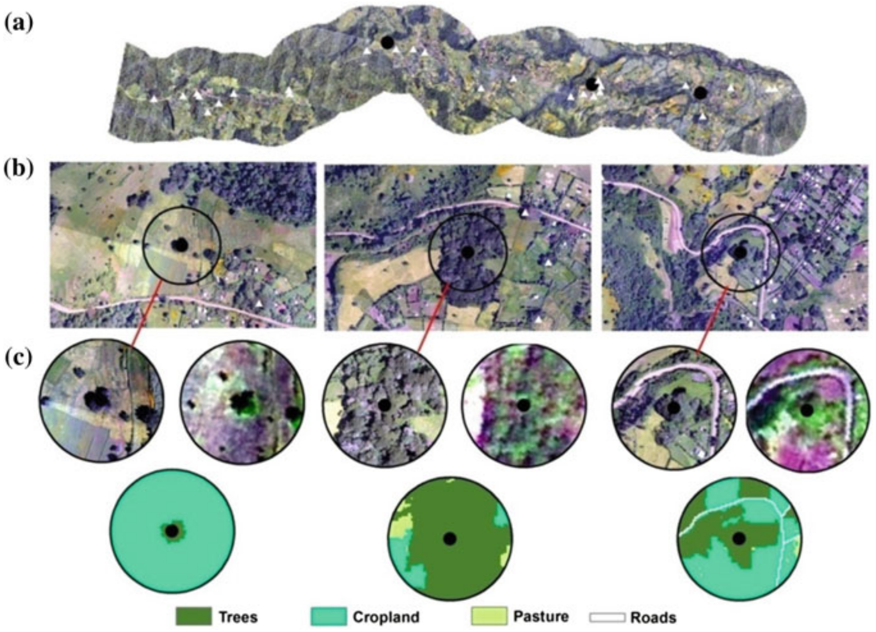

Fig. 2 **a** The 30 plots including plot 20, 13 and 6 with *black dots* distributed on Jimma transect on aerial image, **b** closer view of the three plots with 100 m radius circles, and **c** plot 20 (*left*), 13 (*middle*) and 6 (*right*) with 100 m radius on aerial image with 0.5 m resolution, Spot 5 satellite image with 2.5 m resolution with RGB:432. and LULC classes respectively

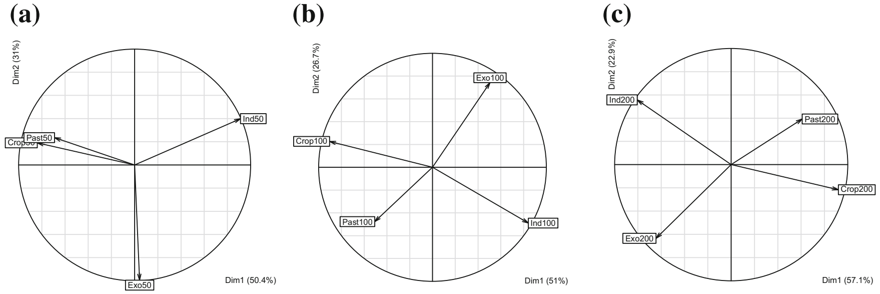

Fig. 3 PCA analysis on LULC variables at 50 m (**a**), 100 m (**b**) and 200 m (**c**) scale on indigenous (Ind) and exotic (Exo) tree canopy coverage, crop land (crop) and pasture land (past)

example, plot 6 has 1963 pixels of trees (12,268.75 m^2 area), 2808 pixels of cropland (17,550 m^2 area), 62 pixels of pasture (388 m^2) and 186 pixels of road (1163 m^2). Generally, plot 13, 30, and 1 have the highest tree cover in the 50, 100 and 200 m radius scale respectively. However, plot 8, 20 and 15 had the lowest tree cover in the three respective scales respectively. Plot 20 had the highest crop cover in the 50 and 100 m radius scale but in the 200 m radius scale, plot 4 had the highest crop cover. Plot 13, 27 and 30 had the lowest crop cover in 50, 100 and 200 m radius scale respectively (data not presented).

The PCA analysis at 50 m radius around each coffee plot (Fig. 3a) indicated that pasture and crop lands were positively correlated and prevented indigenous trees. There was strong negative correlation ($r = -0.71$) between crop land and indigenous trees. The analysis at 100 m radius (Fig. 3b), on the other hand, gave a more precise pattern; the presence of cropped land strongly opposes the maintenance of indigenous trees ($r = -0.79$) while the presence of exotic tree meant the absence of pasture land ($r = -0.30$). In addition, the analysis at 200 m scale (Fig. 3c) produced a more or less similar trend to the scale of 100 m. For example, cropped land was negatively correlated with indigenous trees ($r = -0.80$). Moreover, the first two principal components (PC) explained 81.4, 76.7 and 78.0% of the total variation at scale of 50, 100 and 200 m radius respectively (Fig. 3).

Furthermore, at all scales, the presence of indigenous trees was independent to exotic tree (tree plantation); their correlations were very small. Consequently, total trees (indigenous + exotic trees) were added together at each scale (T50, T100 and T200) (Fig. 4b). However, there was strong correlation between exotic trees at 50, 100 and 200 m radius (Fig. 4a). For example, there was strong positive correlation ($r = 0.97$) between exotic trees at 100 and 200 m. Similarly, there was significant association between indigenous trees observed at the three scales (Fig. 4a). For instance, indigenous tree at 100 m radius was highly correlated ($r = 0.80$) with indigenous trees at 200 m. Therefore, the total trees at the three scales were de-correlated to produce a set of synthetic, linearly uncorrelated two independent variables; Trees1 and Trees2 using the two axis (Fig. 4b). Trees1 represent the global tree canopy density around each plot on the first axis (Dim1) accounting for

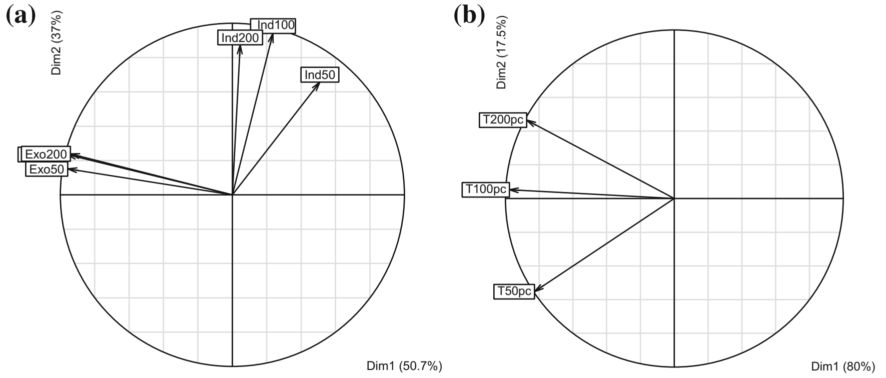

Fig. 4 PCA analysis using indigenous (Ind) and exotic (Exo) trees at 50, 100 and 200 m radius (**a**) and total tree density (T50, T100 and T200) (**b**)

80.01% of the variation while Trees2 represents the tree canopy density close to the plot and at the periphery of the plot on the second axis (Dim2) explaining 17.47% of the total variation (Fig. 4b). The two synthetic uncorrelated variables explained 97.48% of the total variation.

3.2 Cluster Analysis

Cluster analysis using Trees1 and Trees2 variables indicated that the 30 coffee plots were classified into various groups (Fig. 5). The dendrogram showed that there were two big categories of plots at global level; one group of the plots was characterized by high tree density in their surrounding area while the other group was the isolated coffee plots. Multivariate Analysis of Variance (MANOVA) test indicated that only three coffee classes were detected. This test was also supported with our personal observation of the actual coffee plots observed in the field. The MANOVA test showed significant difference when the coffee plots were grouped into three classes at maximum. This classification was also clearly indicated on the dendrogram. The first groups of the coffee plots (coffee class1) were characterized as isolated coffee plots with single/few shade trees; the second group (coffee class2) were characterized as coffee plots within a planted area surrounded with high density of patches of shade trees and the last group of coffee plots (coffee class3) were characterized as coffee plots surrounded by large contiguous forests (Fig. 5). Majority of the coffee plots used for this study were grouped under coffee class2 and class3 (13 coffee plots each) while only few coffee plots (four coffee plots) were categorized under coffee class1.

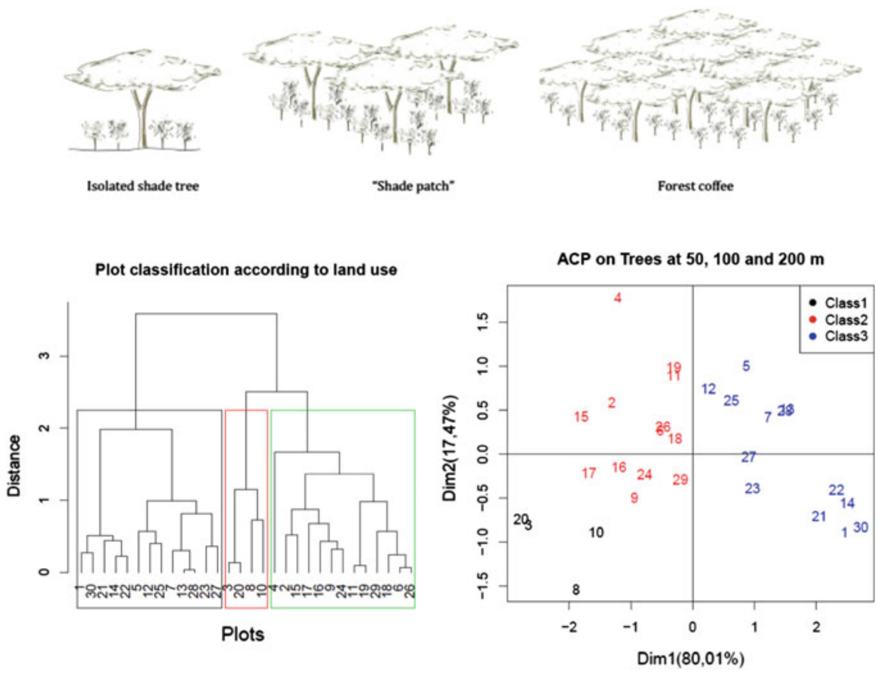

Fig. 5 Classification of coffee plots using Trees1 and Trees2 variables (LULC)

3.3 Climate Condition Among Coffee Classes

The analysis of variance for mean temperature, in both seasons, indicated that there was highly significant ($P < 2e-16$) difference between different coffee classes (Tables 1 and 2). Coffee class1, isolated coffee plots (characterized by low tree density), had significantly higher mean temperature compared to others. On the other hand, coffee class3, characterized by high tree density, gets cooler in both seasons than coffee class2 and class1, which have relatively less tree density (Tables 1 and 2).

Moreover, the analysis of variance indicated that coffee class3, characterized by high tree density, were found to be more humid compared to others, in both years of wet and dry seasons (Tables 1 and Table 2). During the wet season, there was a mean difference of 2.63 and 3.15% between the isolated coffee plots and coffee plots with contiguous forest in 2012 and 2013 respectively (Table 1). But, the difference was relatively small during the dry season as the difference was only 2.35 and 1.76% in 2013 and 2014 respectively (Table 2).

Table 2 Daily mean temperature, relative humidity and wetness duration among coffee classes during dry season at Ageyo-Setema study site in 2013 and 2014

Coffee class	Year					
	2013			2014		
	Temperature (°C)	Relative humidity (%)	Wetness duration (h/day)	Temperature (°C)	Relative humidity (%)	Wetness duration (h/day)
1	22.60^{a}	57.29^{c}	0.012^{b}	20.76^{a}	67.65^{c}	0.050^{c}
2	21.90^{b}	58.14^{b}	0.014^{b}	20.24^{b}	68.41^{b}	0.097^{a}
3	21.57^{c}	59.64^{a}	0.023^{a}	19.75^{c}	69.41^{a}	0.066^{b}

Means sharing the same letter in the column do not differ significantly at 5% probability level using HSD test

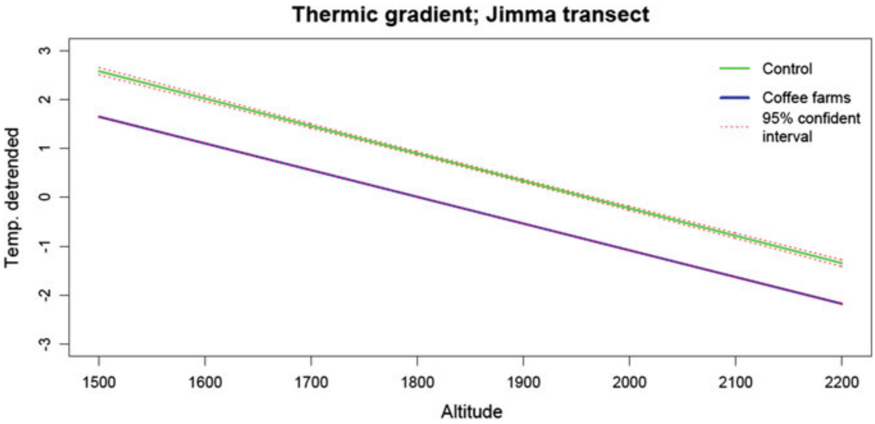

Fig. 6 Mean temperature between control (*open area*) and coffee farms (*under shade*) along altitudinal gradient in Jimma area

Furthermore, the analysis of variance for wetness duration during the wet and dry season showed there was highly significant difference ($P < 2e{-}16$) between the different coffee classes (Tables 1 and 2). The result indicated that there was more wetness duration on coffee class3 both in 2012 and 2013 of wet season compared to the other classes (Table 1). During the dry season, coffee class3 had more wetness duration in 2013 while coffee class2 had more wetness duration in 2014 compared to the others (Table 2).

The comparison of temperature between coffee plots and in the open indicated that there was higher mean temperature under open conditions compared to shaded coffee plot (Fig. 6). A difference of 1 °C was observed between the two contrasting conditions.

4 Discussion

The results of the study indicated that the coffee plots in the study area have a great variety of LULC in their surrounding matrix depending on the level of fragmentation. The existence of different LULC around the coffee plots created a significant impact on the internal microclimate of the coffee plots. Some of the plots are composed of small areas of trees and large areas of cropland and vice versa. Such LULC types might be created due to deforestation for agricultural activities and other ventures such as resettlement. Because of these activities, the coffee produced in the study area is under fragmented land with patchy forests. Farmers use open land either for pasture land or trees plantation (exotic trees) in a competitive manner. On the other hand, the competition for land between cropping and indigenous forests further indicated that farmers are involved in deforestation of indigenous forest to use the land for agriculture crop production. The existence of many patchy coffee plots (fragmented coffee plots) within planted areas in the study area could be used as an indicator for the practice of deforestation. However, the existence of indigenous trees has no impact on the presence of exotic trees, indicating that farmers do not deforest the indigenous forest for tree plantation (exotic trees).

The LULC classified the 30 coffee plots into 3 major groups. The analysis of variance showed significant difference between the three coffee classes for mean temperature, relative humidity and wetness duration during the wet and dry seasons. During the wet seasons (both years) coffee class1, characterized by lower tree density, had a higher mean temperature compared to the other coffee classes. A similar trend of mean temperature variation within the different coffee classes was observed during the dry seasons (both in 2013 and 2014). Hardwick et al. (2015) also reported that human modification of forest results in a change in climate within the forest. Generally, during in the wet season, there was a maximum temperature difference of 1.21 °C among the coffee classes while in the dry season it was 1.03 °C. Such a difference has a practical implication with the implementation of climate change adaptation options. This could also explain that the moderating effect of high density canopy on below canopy microclimate was greater during the wet season compared to the dry season. This might be due to shedding of leaves during the dry season from shade trees; the difference in shade level between the coffee classes was minimal.

On the other hand, the higher tree density in coffee class3 resulted in a higher relative humidity and wetness duration in 2012 and 2013 of the wet season. This might be because of more transpiration by leaves and evaporation from the soil and plant surfaces which add water to the air while cooling and thus lowering the water holding capacity of the air. This resulted in increased relative humidity and wetness duration below the canopy. During the dry season, similar trends of relative humidity and wetness duration among the different coffee classes were observed except for wetness duration of 2014. The highest wetness duration was recorded from coffee class2 in 2014 of the dry season which is difficult to explain. Hence, forest canopy creates a specific understory microclimate that differs from the surrounding local climate. This alteration of local climate is the result of a complex interplay of several stand characteristics and physiographic settings (Arx et al. 2012).

A mean temperature difference of about 1 °C between open and under shade conditions indicates trees have been playing a buffering effect on temperature fluctuation. Along the gradient, the variation was similar showing a possibility of developing shade trees management strategy as an adaption option to climate change impact on coffee at all locations. Therefore, promoting shade tree management as an adaptation option is recommended for small scale coffee growers in Ethiopia.

5 Conclusion

Shade modifies the microclimate of coffee plots. Shade management should be targeted in the strategy to adapt or mitigate climate change in coffee producing country. A better understanding of the landscape structure impact on local climate, which may be used to design and implement landscape management strategies favouring the global performance (production, sustainability) of shade coffee agro-systems.

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