Functional Suitability of Trees in Coffee Shade Systems in different Precipitation Zones of Central Uganda

Technical Report

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Research to Nourish Africa

Hanns R. Neumann Stiftung

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LOCAL AND BOTANICAL NAMES FOR TREES PRIORITISED BY FARMERS

Botanical name	Luganda name	Botanical name	Luganda name
A. chinensis	Mugavu Omuzungu	*F. sur*	Kabalira
A. coriaria	Mugavu	*G. robusta*	Guliveeriya
A. heterophyllus	Ffene	*M. eminii*	Musizi
A. muricata	Kitafeeri	*M. excelsa*	Muvule
A. toxicaria	Kirundu	*M. indica*	Muyembe
A. zygia	Nnongo	*M. lutea*	Musambya
C. calothyrsus	Kaliyandula	*M. oleifera*	Molinga
C. collinum	Nkoola	*M. paradisiaca*	Matooke
C. papaya	Papaali	*P. americana*	Vvakeddo
C. reticulata	Manganda	*P. carribea*	Payinni
C. schweinfurthii	Mpafu	*P. guajava*	Mupeera
C. sinesis	Muccungwa	*S. campanulata*	Kifabakazi
F. mucuso	Mukunyu	*S. cuminii*	Jambula
F. natalensis	Mutuba	*S. spectabilis*	Gasiya
F. ovata	Mukokoowe		

ACKNOWLEDGEMENT

This study has been carried out in Luwero district in central Uganda, under the Global Climate Change Alliance Project implemented by Hanns R. Neumann Stiftung Africa, funded by the European Union and coordinated by the Food and Agriculture Organization of the United Nations.
The purpose of the study was to design climate-smart shade systems for Robusta coffee farmers in central Uganda.

A team of IITA (International Institute of Tropical Agriculture) Uganda led project execution. Staff members at the Hanns R. Neumann Stiftung field office in Luweero also provided technical and administrative support at different stages of the project. Thanks to all farmers that participated in this study. Special thanks to Hanns R. Neumann Stiftung Facilitators that mobilised farmers over the four-month period of this study.

ABSTRACT

Shade-tree based services and constraints in coffee are tree-species specific. Tree species-specific knowledge is necessary to optimize shade-tree composition in a manner that maximises services and minimises constraints of shade-based system.

This study sought to

- characterize the shade systems along a precipitation gradient**,**
- compare both coffee yield and the incidence of Black Coffee Twig Borer (BCTB) between shade systems**,**
- and identify shade tree species that best serve particular functions in different precipitation zones.

Cluster analysis revealed two shade-based systems; the young poly culture and mature poly culture systems. Based on Analysis of Variance, mean coffee yield was not different between systems but the BCTB incidences-based on Poisson modelling-were different. Ranking data analysed using the Bradley Terry model revealed sets of trees that best serve particular functions in the different precipitation zones. Moving towards climate change adaptation, farmers should gradually modify their shade-based systems towards mature poly cultures. It has slightly more yield and, significantly less BCTB.

This study provides a set of trees for optimizing shade-based systems according farmer needs and tree functionality. Mature poly culture designs should consider these sets of trees.

INTRODUCTION

Coffee is the second leading export product from developing countries after oil (ICO 2003). In the case of Uganda, coffee earned 18% of the foreign exchange between 2000 and 2010 (UCDA 2012). Monetary value aside, farmers grow coffee in shade systems (Kalanzi & Nansereko 2014) that render critical ecosystems services; food, soil and water conservation, nutrient recycling (Muleta et al. 2011). However, shade can also have a negative effect on coffee, it can: lower coffee yield by 10-30% (Méndez et al. 2009); increase incidence of the Black Coffee Twig Borer (BCTB) (Parizat et al. 2011) and; compete with coffee for nutrients and water (Smith Dumont et al. 2014).

Climate change complicates the trade-off between services and limitations of shade systems through its impact on coffee systems: prolonged droughts; erratic rainfall patterns; increased temperature (Solomon et al. 2007) and; increased incidence and severity of coffee pests and diseases. In Kasese, Arabica coffee farmers perceived that climate change increased flower abortion and premature ripening (Jassogne et al. 2013). Furthermore, in Robusta systems, BCTB has spread to previously virgin territory (Kagezi et al. 2013) and may also be related to climate change (Ango et al. 2014).

The services and constraints can however be tree-species specific (Smith Dumont et al. 2014) and therefore tree specific knowledge is necessary to develop “optimal” shade tree composition that maximises services and minimises constraints of a shade system (Ango et al. 2014). This study sought to; (i) Characterize shade systems in Luweero and (ii). Generate species-specific knowledge of tree services and constraints to simplify the choice of tree species for “optimal” coffee shade systems. Since the suitability of trees to render certain services depends on local ecological conditions (Vaast et al. 2005) like precipitation; this study accounts for such variation by covering three precipitation zones.

Specifically, the study aimed to

(i) characterize the shade systems in different precipitation zones**,**

(ii) compare coffee yield and BCTB incidences in the different shade based systems**,**

(iii) compare species richness in the different precipitation zones**,**

(v) and identify shade tree species that best serve particular tree services/functions in different precipitation zones.

MATERIALS AND METHODS

Location

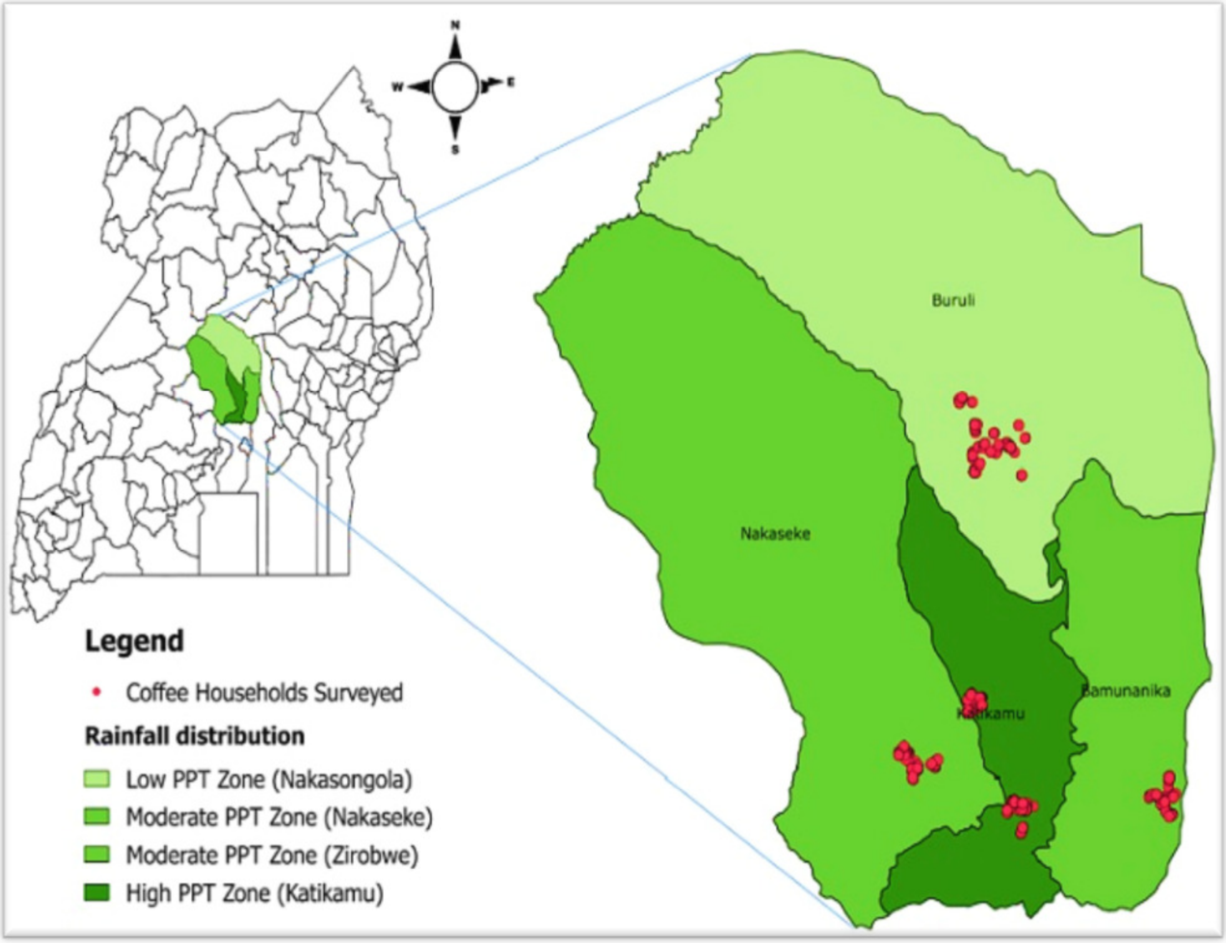


Figure 1: Study area - Greater Luweero area showing location of studied farms in the different precipitation zones averaged over 30 years (1983-2013)

Luweero district lies North of Kampala, between latitude 20 North of the Equator and between 320 to 330 East. Mukono and Wakiso Districts in the South by Kiboga and Mubende Districts in the West, Nakasongola and Masindi Districts in the North and Kayunga District in the East flank it. The total area of Luweero District is approximately 5572.2 km^2 of which 5112.2 km2 is dry land and the rest is rivers and swamps.

Climate and Vegetation

It is a modified equatorial climate. The peak rain period is March – May and October – November. The reliability of rainfall generally declines northwards. Dry seasons occur from December – February and June – July.

Three major vegetation classes exit here:

- **Forest / Savannah mosaic;** It forms part of the areas with an annual rainfall in excess of 1250mm situated in the southern zone of the district. It is typically of mixed tree, thickets, shrubs and grassland formations. For purposes of this study, this area is a high precipitation zone (Figure 1).
- **Moist Combretum woodland;** this occurs in the central moist areas with rainfall between 1125 and 1150 mm per year. Combretum woodland and Terminalia woodland are dominant in this northern Eco tonal zone.
- **Dry Combretum;** this is a variant of the moist Combretum woodland occurring in the dry northern zone with less than 1125 mm of rainfall per year. This wooded savannah is, however, more open and the grass layer continuous.

Sampling Design and Sample Size Determination

The study focuses on Robusta coffee grown largely in central Uganda. The Luweero coffee landscape was chosen because it exhibits a rainfall gradient from low (<1000 mm) to high (>1300mm) rainfall that was used as proxy to climate change. This means that understanding how good practices in the low rainfall zone might inform how the farmers with currently high rainfall must prepare to deal with inconsistent rainfall as it happens with climatic changes. The study therefore covered the three precipitation zones:

- Low precipitation (>1100 mm of rainfall),
- moderate precipitation (between 1100-1200 mm of rainfall),
- and high precipitation (1200-1300).

The study followed two designs: First, on-farm field survey to establish on-farm tree diversity in the coffee landscape: second, a cross-sectional household survey (Bryman 2008) to gather farmers' knowledge about shade trees. The sampling unit of this study was, (i) coffee plot, and (ii) coffee farmer.

Purposively, only small-scale (<2.5ha) farmers were chosen, they comprise about 90% of coffee farmers in Uganda. The study area has three strata based on amount of rainfall received: the low precipitation, Moderate precipitation and high precipitation zones.

The sampling frame is a group of 8000 farmers that collaborate with, Hanns R. Neumann Stiftung, a coffee development organization in Luweero. The sample size was determined by way of calculation based on equation (1) by (Cochran 1963) with adjustment for sample size (equation 2) as in (Israel 1992).

Equation (1): $$a = \frac{Z^2 pq}{e^2}$$ Equation (2): $$\mathrm{n} = \frac{a}{1+\frac{(a-1)}{N}}$$

Where

a = sample before population size adjustment,

Z = 1.96 (from normal distribution),

p = 0.5 (is the estimated proportion of an attribute that is present in the population),

q = 0.5 (1-p) and

e = (0.05) is the desired level of precision

n = derived sample size.

N = 8000 (population size)

Based on these equations, the sample, n, is 366. The study however considered 300 farmers because of financial constraints. The project considered One hundred farmers chosen randomly from each of the three precipitation zones to participate in the local knowledge survey. For the inventory however, it considered only 50 farmers from each precipitation zone.

Data collection methods

The tree inventory covered the plot of interest for each farmer selected to participate in the study. A data collection sheet was used to capture information such as tree species identity, number of individuals per species, diameter at breast height (DBH, measured at 1.3 m from the ground), among others. The team pressed and identified unknown specimens at Makerere University herbarium. A coloured photo was taken for each of the tree species encountered on farm for use in the local knowledge survey. The total number of Banana mats intercropped with coffee was also recorded. Bananas are common shade plants in coffee.

Canopy closure (shade cover) was measured using densiometers and recorded at eight different points each plot of interest.

During the cross-sectional household survey, farmers were interviewed in native (Luganda) language of the dominant ethnic group (Baganda) in the Luweero. A pre-tested (Albertin & Nair 2004) questionnaire in a semi-structured interview (de Vaus 2001) was used to ask farmers about shade trees: advantages and disadvantages; preference of tree characteristics; products; shade tree functions among others.

Coffee Yield

Farmers' coffee yield was determined based on recall data of the last two seasons. The yield provided in Bags was converted to kilograms based on the assumption that each bag of coffee is on average equal to 70 kg of Kiboko.

Incidence of Black Coffee Twig Borer

The total number of coffee shrubs on each farm was recorded along with the total number of coffee shrubs infested by BCTB.

Ranking Exercise

A list of 12 most commonly cited services was generated from farmer's knowledge. These functions related to climate change adaptation and other livelihood needs. For each precipitation zone, a group of twenty most occurring trees was determined and presented to farmers by way of photo representation. Each farmer was asked to choose ten trees that he/she knows best from the group. Farmers selected trees with help of photos taken during the inventory. These photos had representation of the full tree image, tree bole, leaves, flowers, fruits/seed and sometimes the saplings. Farmers ranked the 10 chosen trees in order of importance for each of the pre-selected tree attributes/services (Elliott 2009).

Data Analysis

To determine and compare species richness among precipitation zones, the inventory data was analysed using Estimate S version 9 (Colwell 2013).

Species richness among the three precipitation was compared using species accumulation curves scaled by individuals (Gotelli & Colwell 2001; Chazdon et al. 1998) and extrapolated with 95% un conditional confidence bounds (Shen et al. 2003) until the most species-rich sample attains asymptote. At asymptote, species richness comparison are possible because extrapolation allows for estimation of undetected species during the survey (Colwell et al. 2012). Adjusting for undetected species is especially included because the sampling effort is never exhaustive for total species available. Microsoft Excel 2013 was used to plot estimates computed by Estimate S.

Shade systems were characterised based on the following shade indicators: shade cover (canopy closure); number of shade trees per hectare; average DBH (diameter at breast height) per tree; ratio of coffee to bananas per plot; number of most abundant shade tree species. The indicators were tested for correlation and non-correlated variables identified. The variables were standardized and farms clustered basing on Ward's method (Ward 1963) as executed in 'stats' package of R (R Core Team 2014). The best number of clusters was chosen based on beale index as executed in 'NbClust' package (Tejeda-Cruz & Sutherland 2004) of R statistical software.

The clusters represent shade systems found in the study area. Farms that belong to each cluster were identified and their distribution in the three precipitation zones was determined and tested using the chi-square test of association as executed in the 'stats' package of R (R Core Team 2014).

Coffee yield per hectare in the different shade systems was compared and the difference in mean yield compared using ANOVA after Log transformation of yield to satisfy the normality assumption.

The incidence of BCTB in the different systems and rainfall zones were determined and compared. A general linear regression model of the family Poisson was used to test if pest incidences were significantly different among precipitation zones and among shade based systems.

To determine the best performing group of trees for each function, rank data was first be analyzed using Bradley and Terry model approach (Bradley & Terry 1952). This approach was executed in R statistical software (R Core Team 2014) with BradleyTerry2 package (Firth & Turner 2012) based on three R functions (RankingAnalysis.r, Individuals code.r and Functions.r).

After determining the Rank order, the best groups was delineated qualitatively by set of rules as follows:

- The top group should have at least four trees.
- If the lower boundary of the quasi standard error of current ranked item is lower than the quasi estimate of the next ranked item, then those items belong to the same group. If the lower boundary of the quasi standard error of the current ranked item is higher than the quasi estimate of the next ranked item then such items belong to different groups.
- If the tree right next to the top most group is, a lone group member (occurs alone in its group) it is adjoined to the top most group.

RESULTS AND DISCUSSION

Species Richness among the three Precipitation Zones

Generally, total species richness is in the range of 46 to 54 species in the high rainfall zone, 39 to 42 species in the moderate precipitation zone and 36 to 40 species in the low precipitation zone. Agroforestry tree species richness generally reduces as rainfall reduces as showed by five of six species richness estimators used (Hortal et al. 2006). See Table 1.

Table 1: Estimated species richness for the three precipitation zones based on six non-parametric species richness estimators and their standard Errors

PPT zone	ACE	ICE Mean	Chao 1 Mean	Chao 2 Mean	Jack 1 Mean	Jack 2 Mean
High	47.31(*3.21*)	50.01(*4.5*)	46.51(*2.13*)	49.92(*4.76*)	51.98(*3.18)*	54.17(*6.64*)
Moderate	42.27(*0.22*)	42.32(*0.24*)	42(*0.12*)	42(*0.08*)	42.98(*0.98*)	39.21(*0.00*)
Low	36.5(*1.7*)	37.06(*2.06*)	36.11(*1.5*)	36.93(*2.22*)	38.74(*1.98*)	39.06(*4.17*)

The species accumulation curves below show a comparison among the three coffee agroforestry assemblages at asymptote species richness based on extrapolation as shown. See Figure 3 on page 11.

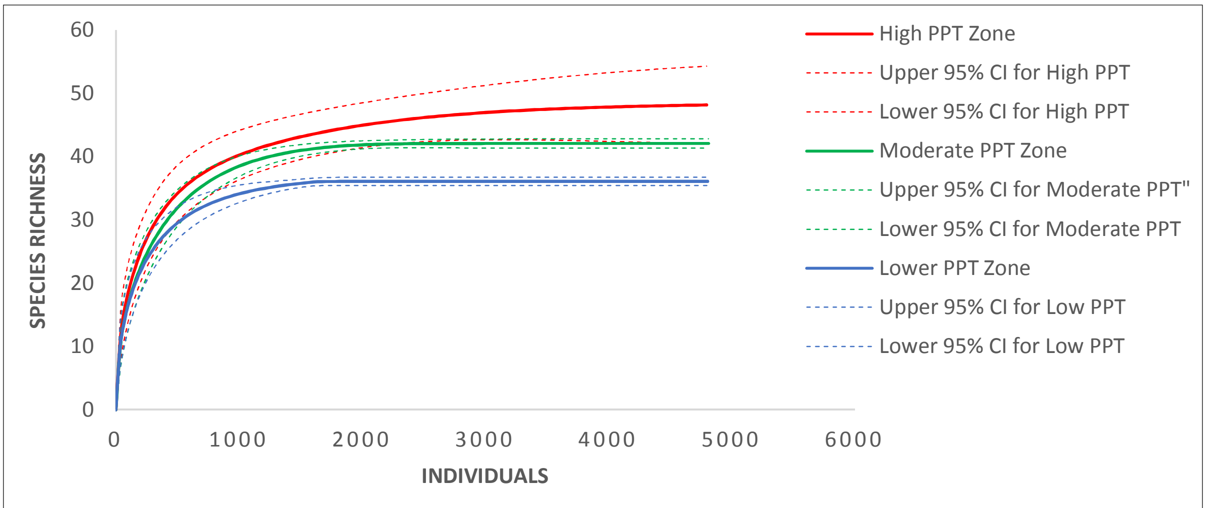


Figure 1: Species accumulation curves and associated bootstrap confidence bounds for the three precipitation zones

If the confidence boundaries of one precipitation zone do not overlap with the others, species richness in those two precipitation zones is significantly different. If the confidence boundary of zone overlaps with the confidence boundary of another zone, species richness of those two zones is not significantly different. At asymptote richness, which is total possible species richness after estimation of undetected species during survey, species richness decreases with rainfall. Species richness of agroforestry assemblages in high and moderate precipitation zones are not significantly different. However, species richness is significantly lower in the low precipitation zone as compared to the high and moderate precipitation zone.

The observed pattern can be explained by the increase in natural plant regeneration in more favourable conditions (Loreau & de Mazancourt 2013) like more rainfall. More specific to coffee farms, increased tree density as the case is for the study area is a major determinant of tree species richness (Méndez et al. 2009).

Although farmers in the low rainfall zone have fewer tree species intercropped in their coffee, species richness is not directly related to functional diversity (Loreau & de Mazancourt 2013). This means even with fewer species, farmer could access all needed functions if such trees are chosen to balance tree functions needed on their farm.

Characterization of Shade-based Coffee Systems in Greater Luweero

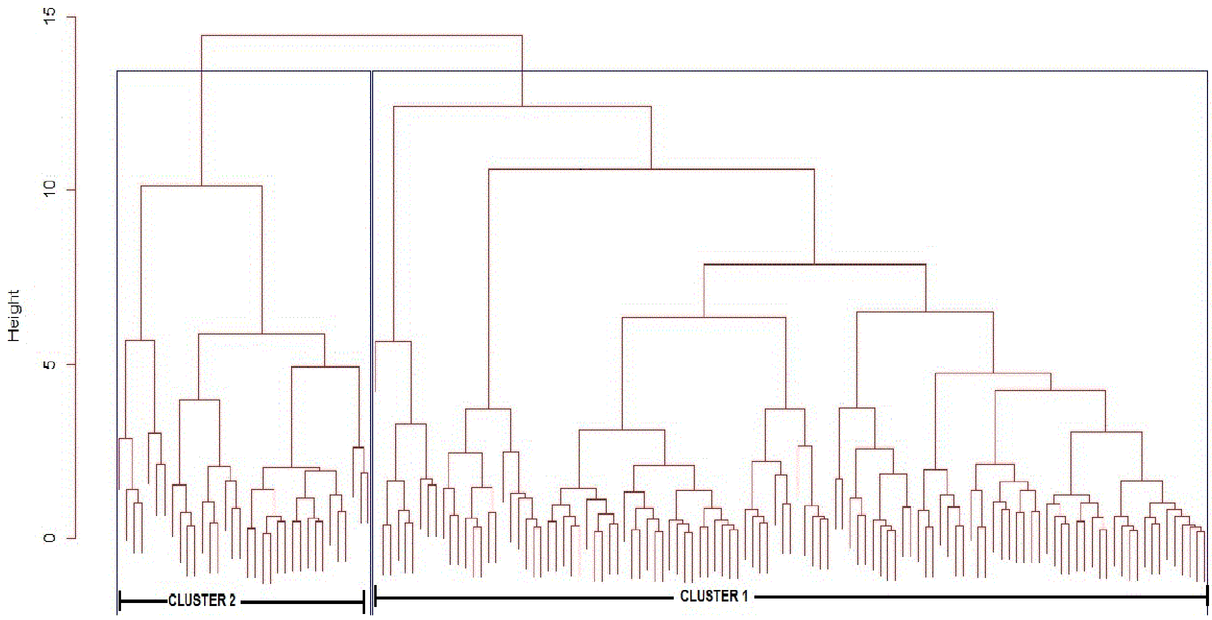


Figure 2: Cluster analysis of coffee farms in the coffee landscape of greater Luweero

A cluster analysis of shade indicators reveals two clusters of farms as shown in Figure 4. Cluster 1 is bigger than cluster 2. These clusters are shade based coffee systems described in Figure 5. Cluster 1 is the young poly culture and cluster two is the mature poly culture.

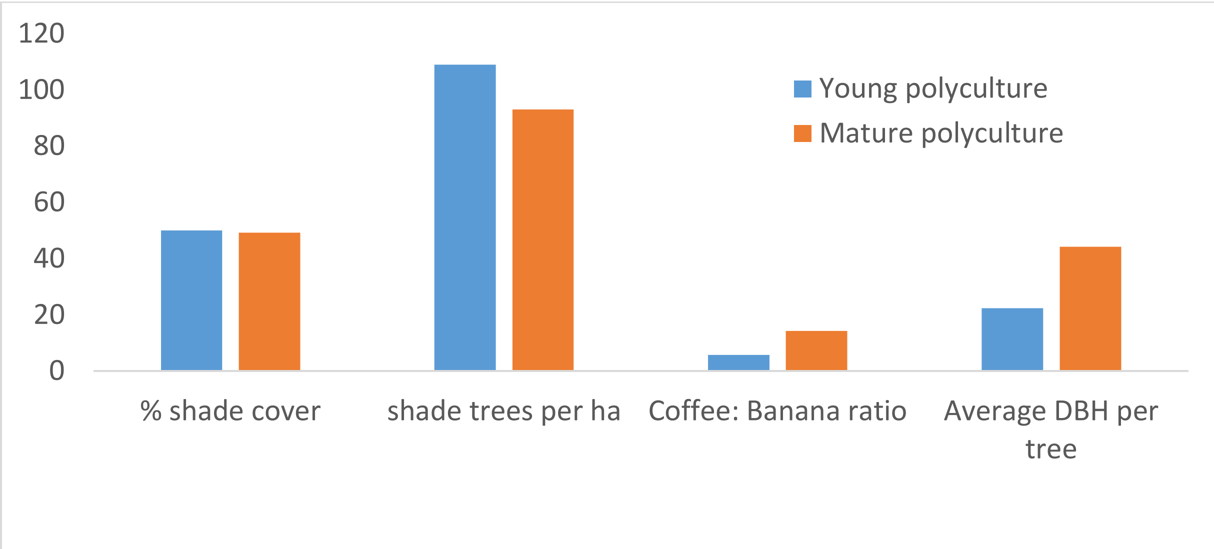


Figure 3: Description of shade based systems as defined by shade indicators

The young poly culture has more shade trees per hectare, more bananas intercropped with coffee and smaller trees. The mature poly culture has fewer shade trees, fewer bananas intercropped with coffee and bigger shade trees. Regardless of shade system, farmers maintained a similar shade cover of about 40-60% because the trees in mature poly culture are fewer but older. The 40- 60% shade level is attainable by either altering number of trees (increase or decrease) or by regulating the age of on farm trees. With younger trees, you need more trees but as they get older, you need fewer trees.

Although 40-60% shade cover was considered good enough to supress pest in other studies (Staver et al. 2001), the structure of that shade as defined by the shade based indicators was characterised and compared for difference in yield and BCTB incidences.

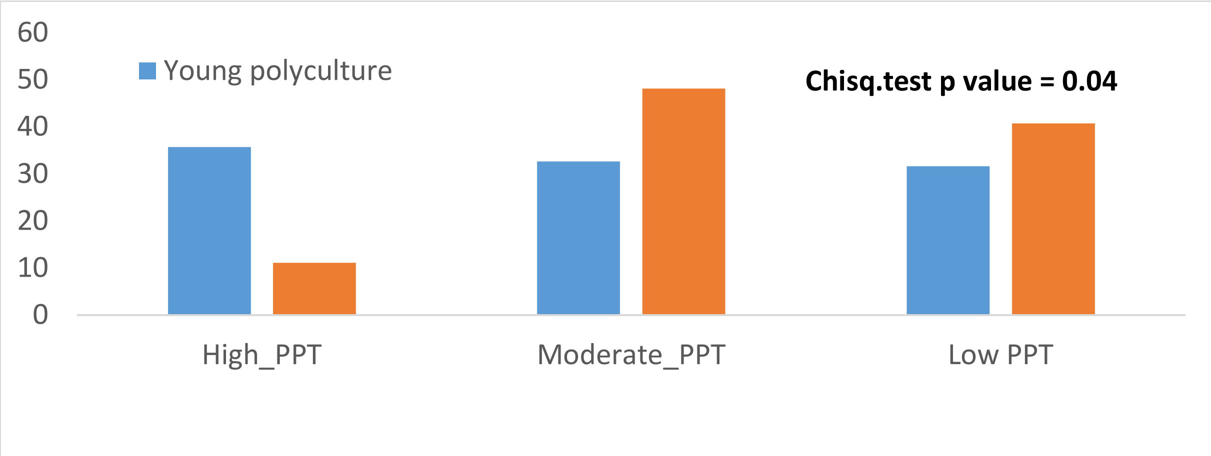


Figure 4: Distribution of shade systems across precipitations zone

The young poly cultures spread out evenly across all precipitation zones but the mature poly cultures are more common in moderate and low precipitation. The chi square test of independence revealed that shade-based systems are significantly dependent on precipitation. It is less likely to meet mature poly cultures in the high precipitation zone.

With low rainfall, the competition between coffee and trees for water is more severe and farmers continually weed out any unwanted trees from their coffee. The number of trees naturally regenerating on such farm is also lower than in the high precipitation zone. These two factors combine to yield fewer trees in such areas.

To test whether this trend is of advantage, coffee yield and the incidence of black coffee twig borer were tested among precipitations zones and between shade-based systems. See figures 7, 8 & 9.

Incidence of Black Coffee Twig Borer in different Precipitation Zones

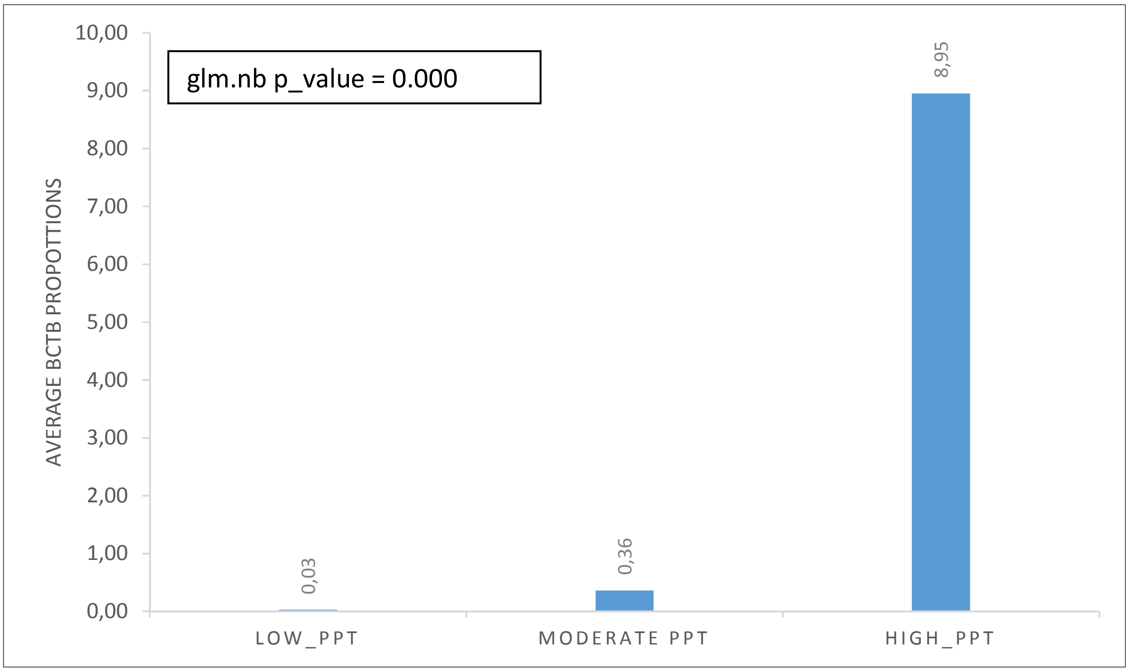


Figure 5: Comparing Black Coffee Twig Borer incidences in different precipitation zones

The data show more incidences of black coffee twig borer in the high precipitation zones than in the moderate precipitation and more in the moderate than on low precipitation zone. However, rainfall does not cause BCTB. The difference in BCTB incidence is statistically significant at 5% as shown by the p value from the negative binomial model. It is more likely to meet BCTB infested coffee farms in the high precipitation zones than in the low precipitation zones.

This is the first study to document the association of BCTB with relatively higher rainfall. More likely, the pest thrives in areas of relatively higher humidity that prevail in coffee farms that receive relatively higher rainfall. Alternatively, the ambrosia fungus that the pest farms(Greco & Wright 2015; Hara & Beardsley 2010; Hara & Beardsley 1979) might grow better in relatively humid conditions. Evidence to support these hypotheses or any other explanation of the relationship could guide pest management (Teodoro et al. 2008) but it is undocumented so far.

Incidence of the Black Coffee Twig Borer in different Shade Systems

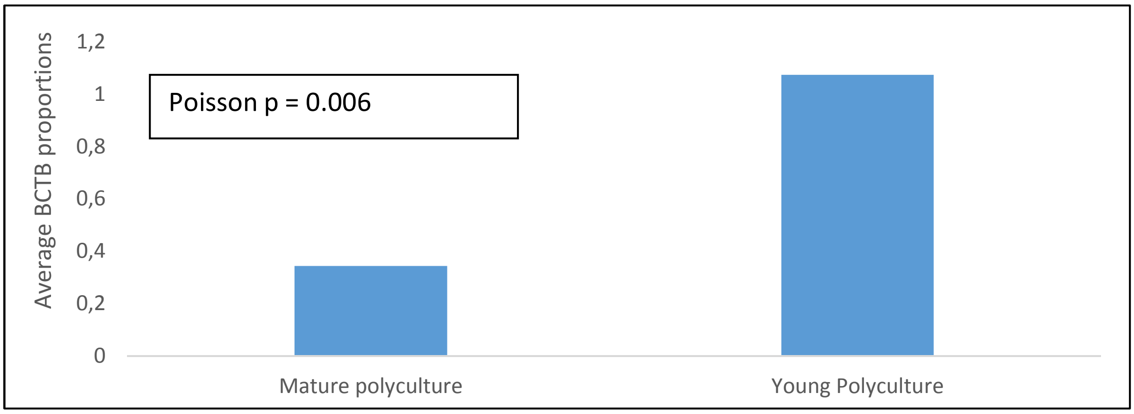


Figure 6: Black Coffee Twig Borer infestation in the different shade-based systems

The data show that mature poly cultures are less prone to infestations by the twig borer than young poly cultures. The differences are significant at 5% confidence level with a Poisson regression p value of 0.006.

The twig borer thrives in young poly cultures possibly because these farms are congested and continually humid just like the farms in high precipitation zone. They possibly render a more conducive environment for the growth of ambrosia fungi that the twig borer feeds on (Greco & Wright 2015). Since the pest is essentially dependent on fungus farming, conditions that deter the growth of that fungus would greatly reduce its populations (Bote & Struik 2011).

Coffee Yield in the different Shade-based Systems

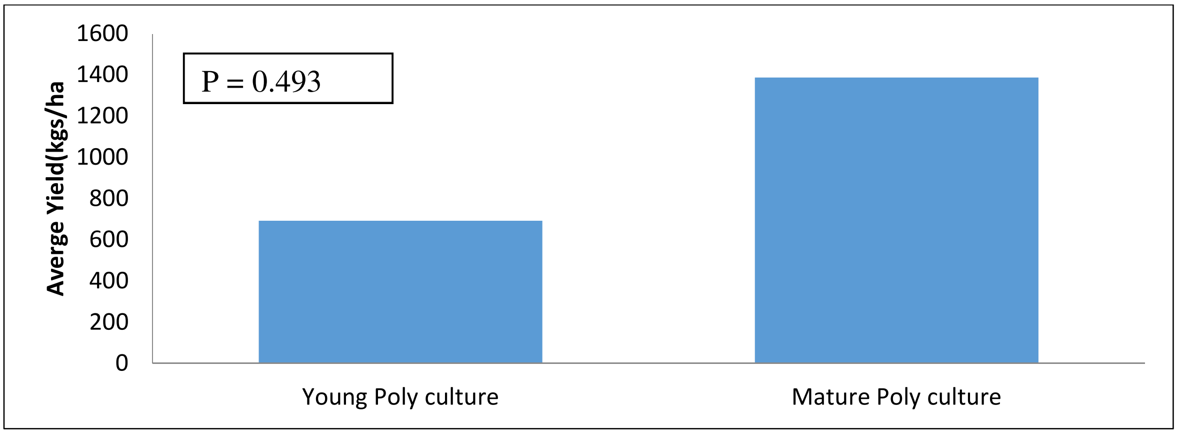
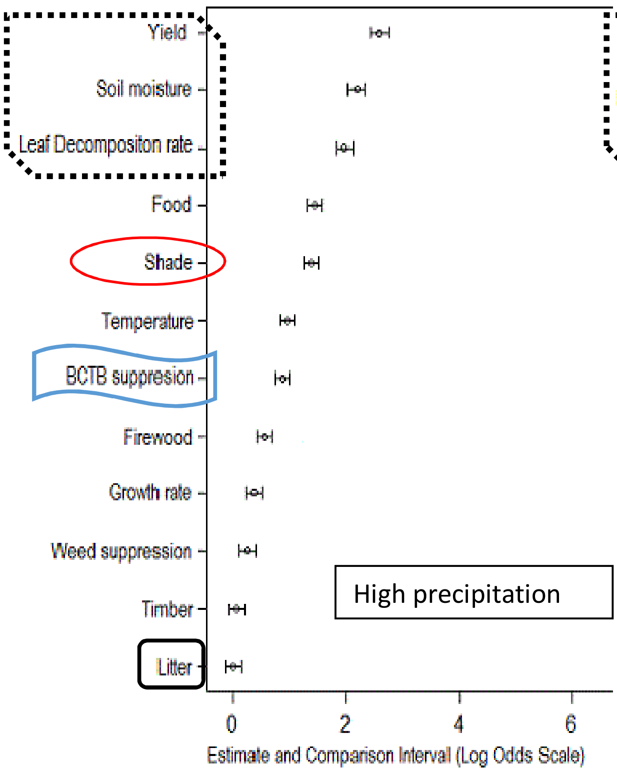


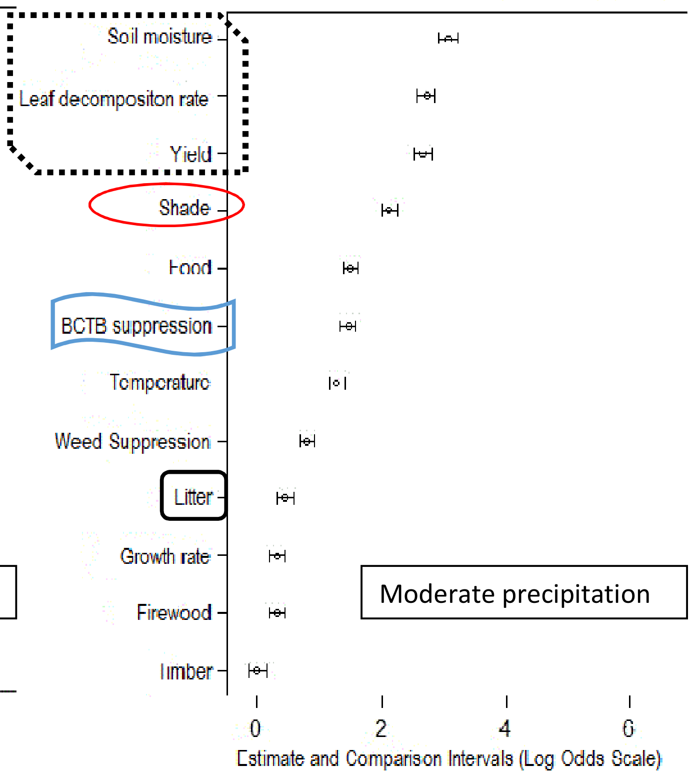
Figure 7: Comparison of mean yield of coffee per hectare between shade-based systems

Generally, the mean coffee yield was not statistically significant between shade-based systems; it was generally higher in mature poly culture shade-based system. Unlike studies (Méndez et al. 2009; DaMatta 2004) that compare shaded and un-shaded, this data show that even within shaded systems, yield may vary. Other studies showed lower coffee yields for shade levels above 50% (Soto-Pinto & Perfecto 2000) but didn't describe that particular shade system. As shown here, the same shade levels could be of different shade systems. The young poly cultures, which have similar shade levels with mature poly culture, showed lower yields. This is partly because of the many young (juvenile) shade trees(Smith Dumont et al. 2014) that compete with coffee for water and nutrients (Ango et al. 2014).

Given the insight of a better shade-based system (Mature poly culture), and the tree species richness of coffee agroforestry, suitability of trees for certain functions is addressed through Bradley Terry modelling of tree ranking by farmers. First, farmers ranked tree-functions in order of importance as shown in Figure 9.

Bradley Terry Model: Ranking Outputs





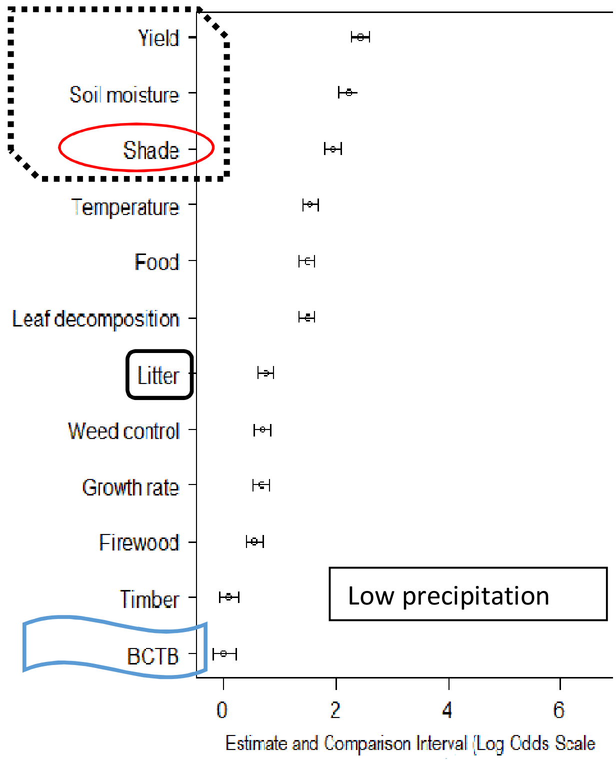


Figure 8: Rank order of coffee-agroforestry tree functions in the three precipitation zones based on quasi estimates and quasi standard errors generated by Bradley and Terry Model II

Farmers in different precipitation zones prefer different tree services because they face different environmental stresses. The ranking of some attribute like food are relatively stable: they are not so sensitive to changes in precipitation.

Some critical tree functions however, vary with precipitation. In the high precipitation zone, the top three functions are; increasing coffee yield, preserving soil moisture and decomposing leaf litter in that order. In the moderate precipitation zone, soil moisture preservation takes the lead, quick leaf decomposition follows and increased yield comes third. In the low precipitation zone, shade quality comes in at third, soil moisture preservation as second and increased yield as first. The relative importance of shade quality and amount of leaf litter in the coffee farms increases as precipitation reduces while the need to suppress the Black Coffee Twig Borer reduces with rainfall. This agrees with figure 5 that shows low BCTB prevalence in the low precipitation zones. The ranking of each function revealed a group of trees that serve(s) certain function(s) best. See also Table 2 below.

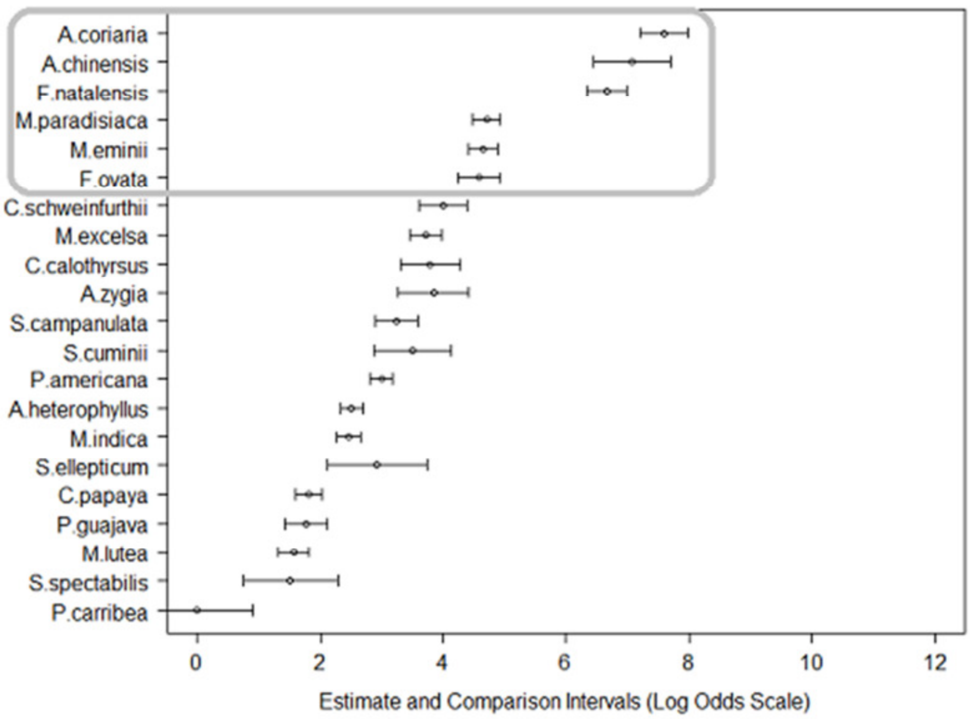


Figure 9: Farmers' ranking of coffee-shade plants in the high rainfall zone for the functions of increasing yield: For tree rankings of other functions in the high rainfall zone, see Appendix A.

Figure 9 is an example of the graphical output of the Bradley Terry model for the function of increased yield in the high rainfall zone. It shows from the best to worst ranked trees. For every function considered, a similar graph is plotted (Appendix A) for each precipitation zone. The graph depicts the best performing set of trees for each function. For increasing coffee yield, farmers of high precipitation zone prioritised Albizia coriaria, Albizia Chinensis, Ficus natalensis, Musa paradisiaca, Maesopsis eminii and Ficus ovata. This group of trees is therefore the most appropriate for increasing coffee yield in the high rainfall zones.

For each function considered, a certain set of trees ranked the best. See Table 2 (next page).

Table 2: Agroforestry trees that best serve certain functions in different precipitation zones.

Tree Function	High PPT Zone	Moderate PPT Zone	Low PPT Zone
Amount of litter	*A. heterophyllus* *M. indica* *F. natalensis* *A. coriaria*	*M. indica* *A. heterophyllus* *A. coriaria* *F. natalensis* *A. chinensis* *M. excelsa* *F. ovata* *C. schweinfurthii*	*F. mucuso* *A. heterophyllus* *A. coriaria* *M. indica*
Firewood	*M. eminii* *A. coriaria* *F. natalensis* *M. lutea* *S. spectabilis* *M. excelsa* *A. chinensis* *M. indica* *A. zygia*	*A. coriaria* *M. eminii* *F. natalensis* *A. chinensis* *M. excelsa* *M. lutea*	*M. eminii* *C. collinum* *A. coriaria* *A.zygia* *F. natalensis* *M. excelsa* *S. spectabilis* *M. lutea*
Food	*M. paradisiaca* *A. heterophyllus* *C. papaya* *M. indica* *P. americana*	*M. paradisiaca* *A. heterophyllus* *C. papaya* *M. indica* *P. americana* *S. cuminii*	*M. paradisiaca* *M. indica* *A. heterophyllus* *C. papaya* *P. americana*
Growth rate	*M. paradisiaca* *C. papaya* *C. calothyrsus* *A. chinensis* *F. natalensis* *M. eminii* *A. heterophyllus* *S. spectabilis* *P. americana*	*M. paradisiaca* *C. papaya* *C. calothyrsus* *M. eminii*	*M. paradisiaca* *C. papaya* *M. eminii* *A. heterophyllus* *F. natalensis* *M. indica* *C. reticulata* *C. sinesis* *A. muricata* *P. guajava* *S. spectabilis* *P. americana*
Quick leaf decomposition	*C. calothyrsus* *A. coriaria* *F. natalensis* *A. chinensis* *S. spectabilis* *M. eminii* *C. papaya* *A. zygia* *M. paradisiaca* *S. campanulata*	*A. coriaria* *A. chinensis* *F. natalensis* *A. zygia* *C. calothyrsus*	*A. coriaria* *F. natalensis* *C. papaya* *M. eminii* *S. spectabilis* *F. mucuso*

Tree Function	High PPT Zone	Moderate PPT Zone	Low PPT Zone
Shade quality	*A. coriaria* *F. natalensis* *A. chinensis* *M. eminii* *F. ovata* *A. zygia* *C. schweinfurthii* *M. excelsa* *M. paradisiaca*	*A. coriaria* *F. natalensis* *A. chinensis* *M. eminii* *F. ovata*	*A. coriaria* *F. natalensis* *F. mucuso* *M. eminii* *F. ovata* *S. campanulata* *M. excelsa*
Soil moisture	*A. coriaria* *F. natalensis* *A. chinensis* *M. paradisiaca*	*A. coriaria* *F. natalensis* *A. chinensis* *M. paradisiaca* *F. ovata* *C. calothyrsus*	*F. mucuso* *A. coriaria* *F. natalensis* *F. sur*
Temperature	*F. natalensis* *A. coriaria* *M. indica* *A. heterophyllus* *A. chinensis*	*M. indica* *A. coriaria* *F. natalensis* *A. heterophyllus*	*F. mucuso* *F. natalensis* *A. coriaria* *M. indica*
Timber	*M. excelsa* *A. coriaria* *M. eminii* *M. lutea* *P. carribea* *C. schweinfurthii*	*M. excelsa* *A. coriaria* *M. eminii* *C. schweinfurthii* *G. robusta* *P. carribea* *M. lutea*	*A. coriaria* *M. excelsa* *M. eminii* *A. toxicaria* *P. carribea* *M. lutea* *F. ovata* *F. mucuso*
Weed control	*M. indica* *A. heterophyllus* *A. coriaria* *M. excelsa* *F. natalensis*	*M. indica* *A. heterophyllus* *F. natalensis* *A. coriaria* *F. ovata* *M. excelsa*	*A. coriaria* *F. mucuso* *M. indica* *A. heterophyllus* *F. natalensis*
Yield	*A. coriaria* *A. chinensis* *F. natalensis* *M. paradisiaca* *M. eminii* *F. ovata*	*A. coriaria* *F. natalensis* *A. chinensis* *M. paradisiaca*	*A. coriaria* *F. natalensis* *F. mucuso* *M. eminii* *F. ovata* *F. sur*

Note: ranking for function of suppressing the Black twig borer was inconsistent and I caution against following it but ***Error! Reference source not found.*** nevertheless shows that set of trees together with all others.

The data show particular groups of trees that serve certain functions best. The species composition for such groups varies with precipitation.

Among all the trees that farmers ranked highly. Two trees stand out the most: F. natalensis (Mutuba) and A. coriaria. These trees rank highly for most of the functions in all precipitation. Naturally, they A. coriaria can regenerate on its own and F. natalensis can is easy to propagate by cuttings and farmers already know how to propagate it. However, farmers complained that F. natalensis is likely to topple and be uprooted during storms. Ultimately, we need to raise the trees from seed and not cuttings. Trees raised from cutting do not have a taproot but trees raised from seed have a taproot and can withstand stormy rains longer. However, F. natalensis may also withstand stormy rains if pruned continually to reduce canopy thickness. The pruning should happen after the rainy season starts and not in the dry season when coffee needs shade.

Previous studies (Kindt et al. 2006) have contributed to our knowledge of the existence of different functional groups. This study identifies the best performing tree species for particular functions derived from trees. Subsequent work should focus on combining this kind of tree rankings into a decision tool that considers farmers needs and weighs up the most suitable set of trees. The variation displayed in farmer needs (figure 9) supports earlier efforts for greater recognition of people within the coffee landscape for both biodiversity conservation (Garcia et al. 2010) and productivity of coffee.

Careful scrutiny of species identities of the various use-groups, revealed over 34 different species ranked among the top tier. Adopting these sets of trees for coffee systems will result into better links between development and conservation goals (Kindt et al. 2006).

CONCLUSIONS AND RECOMMENDATIONS

The coffee landscape of Luweero has two shade-based coffee systems; the young poly cultures the mature poly cultures. These systems perform differently for coffee health and productivity. The mature poly cultures are more common in the low rainfall zones than in the high rainfall zone.

On average farms have between 40-60 % shade cover. Unlike common heresy, the Black Coffee Twig Borer infestations link directly with the composition of shade systems and not just shade cover. Farms with almost similar shade cover can have different BCTB infestation levels depending on which shade systems is at play. For instance, BCTB thrives in high precipitation zone and in the young poly cultures because higher humidity might favour either the twig borer and/or the ambrosia fungus that the twig borer feeds on (Greco & Wright 2015). Further investigation to unmask this mystery is necessary for better coffee health and productivity. Meanwhile, farmers should adopt mature poly cultures. The culture of removing big older trees from the farm to reduce shade may not always reduce the level of BCTB infestation. It is better to maintain bigger and/or taller trees if they meet farmer needs, but reduce the younger and more competitive shade trees. **Caution**: mature poly culture means higher proportion of older trees than young ones of a particular species but not taking out all young trees. These mature poly cultures have fewer trees but are more functionally diverse.

Mean coffee yield is not significantly different among the shade-based systems but is relatively higher among the mature poly cultures. Farmers should transform their farms to attain mature poly culture status because it is less prone to the black coffee twig borer and coffee yields are slightly better.

Mature poly culture designs should base on retaining shade trees found to satisfy farmer needs. See Table 2.

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Appendix A – D:

Available on request.