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Economies and Ecologies of Indigenous vs Exotic Shade Trees: Experiences from Coffee Based Agro-Forestry Systems in Kodagu

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Abstract The present study was carried out to understand the economies and ecologies of indigenous vs exotic shade trees in coffee agro-forestry system of Kodagu. The primary data was collected from 60 Arabica and 60 Robusta growers between March to April, 2017. On the economic front, the study analyzed the influence of exotic and indigenous shade trees on productivity of coffee. The exotic silver oaks (*Grevillea robusta*) had adversely impacted productivity of Arabica (Commercially, there are 2 cultivated species of coffee viz., Arabica and Robusta coffee) variety of coffee. In contrast to the this, initially, the number of silver oak trees per ha positively influenced productivity of Robusta. However, further with the increase in number of silver oaks (beyond 121 trees per ha), the productivity of Robusta also declined. The inflection point on the number of silver oaks per ha to the productivity of Robusta was found to be 121 trees per ha. The number of indigenous trees per ha had a positive influence on productivity of Arabica. The dadap trees (*Erythrina* spp.), generally used as temporary shade in coffee estates, however had a positive influence only on productivity of Arabica. While the redeemed land tenure system significantly influenced the productivity of Robusta coffee. On the ecological front, the study analyzed the influence of indigenous and exotic shade trees on the incidence of White Stem Borer in Arabica. The results found that the incidence of White Stem Borer in Arabica were lower in estates that comprised of higher number of indigenous trees. Though the exotic silver oaks positively influenced the borer attack, was however found to be insignificant. Interestingly, the incidence of borer attack was found to be higher in redeemed Arabica estates. The study recommends the government to re-look into the tree standing rights in the private coffee plantations, encourage more of native shade by supplying indigenous shade tree species to the growers, while also restrict for the limited cultivation of exotic silver oaks in coffee estates.

Keywords Redeemed, Indigenous, Silver oaks, White Stem Borer, Dadaps.

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Introduction

Traditional shade grown coffee plantations in Kodagu harbor about 70–1200 shade trees per ha (Nath et al. 2010), comprising of diverse shade vegetation within plantations (Elouard 2000, Bali et al. 2007, Nath et al. 2010). Such shade species diversity could furnish a wide range of ecosystem services that possibly impacts productivity (Boreux et al. 2016). More importantly, the shade trees in coffee plantations are an indispensable factor that determines productivity and sustainability (Evizal et al. 2016, Jezeer and Verweij 2015, Hundera et al. 2013). However, owing to commercialization in coffee plantation, the indigenous shade trees are being replaced by exotic silver oak (*Grevillea robusta*) species, that exemplifies the trade-off between economic and sustainability objectives in the plantation sector. Even at a macro level, concerns have been raised about global shrink in native shade

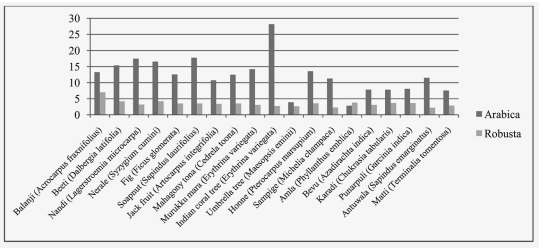

Fig. 1. Major indigenous shade trees (Only major indigenous shade tree species are shown in the Figure) per ha in Arabica and Robusta estates (number of indigenous shade trees/ha). (Source: Survey results).

tree cover, specifically in coffee agro-forestry system and its possible impact on biodiversity, ecosystem services and livelihoods. Besides, shade trees being a beneficial aspect of climate change adaptation (Jha et al. 2014).

The coffee agro-forestry accommodates a set of both indigenous and exotic shade tree species (Rigal et al. 2018). The indigenous (native) shade trees are the ones that are found to be natural to a particular region or the ones that occur naturally in a particular place. The major indigenous shade trees in our studies are shown in Fig. 1. In contrast to these species, the exotic trees are the ones that are introduced to the region (non-native) probably from other countries and are alien to the country. The major exotic shade tree in coffee plantation is silver oak (*Grevillea robusta*). The invasion of *Grevillea robusta* into coffee agro-forestry has caught much attention in the recent years and its impact on productivity of coffee are to yet to be ascertained.

Several studies (Bote and Struik 2011, Evizal et al. 2016) have documented the influence of shade trees on productivity of coffee. Nevertheless, as mentioned earlier, there has been a gradual transition in the type of shade trees which predominates due to economic reasons. Now segregating shade trees into indigenous and exotic trees, do they have any impact on productivity of Arabica and a Robusta variety of coffee is the key question. This paper finds plausible answer to the above question, which have important policy implications for conserving indigenous shade trees and while also maintaining the optimum magnitude of silver oaks in the estates in order to achieve a

Table 1. Socio-economic profile of Arabica and Robusta growers. (Source: Survey results).

Details	Arabica (N=60)	Robusta (N=60)
Average size of holdings (ha)	18.15	11.56
Average household size (numbers)	5.12	4.70
Age group of members (%)		
<16 years	22.47	20.57
16–60 years	56.03	59.22
> 60 years	21.50	20.21
Caste (% of households)		
SC or ST	0	0
OBC	46.67	45.00
Minority	5.00	8.33
General category	48.33	46.67
Education status of members (%)		
Illiterate	0	0
Lower primary	3.33	0
Upper primary	5.00	1.67
High School	11.67	11.67
Pre-University College	15.00	23.33
Graduate	61.67	51.67
Post-Graduation	3.33	11.66

delicate balance between ecological sustainability and economic viability in scaling-up coffee agro-forestry systems, as well as securing sustainable livelihood for coffee-farming families.

On the ecological front, the study estimates the impact of indigenous and exotic shade trees on incidence of White Stem Borer (*Xylotrechus quadripes*), (White Stem Borer (*Xylotrechus quadripes*) is a major pest of Indian Arabica and does not attack Robusta variety of coffee) the most destructive pest and ranked to be number 1 and major production constraint in *Coffea arabica* (Murphy et al. 2008). For instance, our survey found that unable to bear the incidence of White Stem Borer (WSB), the Arabica growers uproot the superior quality Arabica and replace them with low-priced and pest resistant Robusta variety of coffee. In other words, rapid shift from Arabica to Robusta variety is taking place to the extent that much demanded Arabica variety coffee is under high risk of extinction (Davis et al. 2012). Nonetheless, Venkatesha (2010), Murphy et al. (2008) advocated that Integrated Pest Management (IPM)

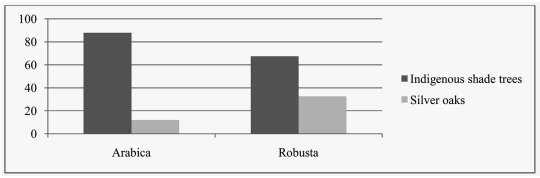

Fig. 2. Percent of shade trees in Arabica and Robusta estates (%). (Source: Field survey).

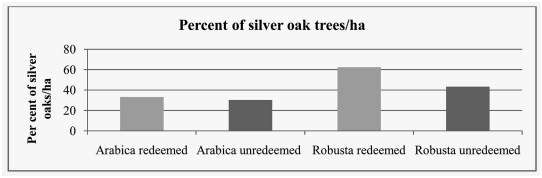

Fig. 3. Percentage of silver oak percent of silver oaks = (Number of silver oak trees per ha / Total number of shade trees per ha) *100 trees under different land tenure systems. (Source: Survey results).

such as maintenance of optimum shade trees in coffee plantations could reduce the incidence of WSB attack in Indian Arabica. Thereby, the study classes the shade trees into indigenous and exotic trees to determine its influence on incidence of coffee White Stem Borer (WSB).

Main objectives

With this background the study attempts to address the following objectives: To understand the influence of indigenous shade and exotic shade trees on productivity of coffee. To analyze the influence of shade and exotic trees on White Stem Borer in Arabica variety of coffee.

Materials and Methods

The survey employed both qualitative (in-depth interviews, extensive field observations, review of documents) and quantitative data collected among several actors in Kodagu for a period between March-July, 2017 period. A semi-structured questionnaire was prepared and pre-tested. The survey respondents were identified through multi-stage stratified random sampling method, based on the latest official records of Coffee Board and Codagu Planters Association (CPA), Madikeri. In the first stage, 3 Arabica and Robusta liason zones were selected. Two villages were randomly selected from each of the liason zones. Finally, 10 farmers were selected from each of these villages. A total of 120 coffee holdings were visited during the survey, of which 60 were Arabica holdings and 60 were Robusta holdings. Regression analysis was used to determine the influence of indigenous and exotic shade trees on productivity of coffee and incidence of White Stem Borer. The secondary data pertaining to the study were collected from publications of Indian Coffee Board and earlier literature in the area.

The paper is organized in the following order: The next section presents background information of respondents, followed by current status of indigenous and shade trees among the surveyed estates, influence of indigenous and exotic shade trees on productivity

Table 2. Influence of indigenous trees and shade trees on productivity (kg/ha) on Arabica and Robusta variety of coffee: Regression analysis (Y = Productivity kg/ha). *** and ** Significant at 0.01 and 0.05 level respectively.

Variable	Co-efficient	t value	Level of significance	Co-efficient	t value	Level of significance
Constant	3.38	33.59***	0.00	2711.64	26.69***	0.00
Silver Oaks	– 0.01	– 4.63***	0.00	2.41	1.77*	0.08
Silver Oak Square	–	–	–	– 0.01	– 1.65*	0.10
Indigenous trees	0.04	2.68***	0.01	– 1.55	– 1.84*	0.07
Dadaps trees [8]	0.71	26.83***	0.00	– 0.97	– 1.49	0.14
Dummy on redeemed land	0.00	– 0.33	0.74	421.69	7.15***	0.00
R-Square		0.96			0.63	
F Value		327.28			18.21	
Number of observation		60.00			60.00	

Table 3. Influence of indigenous and exotic shade (trees per ha) on incidence of White Stem Borer (WSB) in Arabica (Y = Uprooted Arabica trees per ha).

Variable	Co-efficient	t value	Level of significance
Constant	– 11.10	– 2.32**	0.02
Ln indigenous trees (number of trees per ha)	–0.19	– 2.30**	0.02
Ln silver oaks (number of trees per ha)	0.015	0.37	0.71
Ln dadaps (number of trees per ha)	–2.07	– 3.09***	0.003
Ln cost of pruning (Rs/ha)	2.48	3.46***	0.001
Ln average annual rainfall (mm)	0.17	0.523	0.60
Ln age of coffee trees (years)	–0.26	– 1.24	0.21
Dummy on redeemed land	0.59	4.42***	4.96E-05
R-Square	0.50		
F Value	7.66		
Number of observations	60		

of coffee, influence of shade trees on incidence of White Stem Borer (WSB) in Arabica and the last section presents conclusions and policy implications.

Background information of respondents

The demographic and socio-economic characteristics of selected households are presented in Table 1. The average size of land holdings among Arabica and Robusta growers were 18.15 ha and 11.56 ha respectively. The average household size of the total sample among Arabica growers was found to be larger (5.12 members), than Robusta (4.70 members). On an average, about 56.03 and 59.22% of household members in Arabica and Robusta respectively belonged to working age group of 16–60 years, followed by senior citizen (>60 years) comprising of 21.50% in Arabica and 20.21% of the members in Robusta. About 46.67 and 45.00% of growers in Arabica and Robusta belonged to the OBC category, followed by General (48.33 and 46.67% in Arabica and Robusta respectively), while at an overall level only 6.66% belonged to minorities. In terms of education, about 61.67 and 51.67% of Arabica and Robusta growers were graduates.

Status of indigenous and exotic silver oak (*Grevillea robusta*) shade trees among surveyed estates

A survey of 120 coffee estates (60 Arabica and 60 Robusta estates) revealed that, Arabica estates maintained a higher shade tree density (360 shade trees/ha), compared to Robusta (200 shade trees/ha), besides the Arabica estates comprised of higher (88%) of indigenous shade trees, as compared to Robusta (67.41%). While, the fast growing, exotic Australian species silver oak (*Grevillea robusta*) was the preferred shade tree in Robusta estates, that constituted for 32.59% of total shade trees (Fig. 2). Not surprisingly, the native shade trees were being replaced by exotic silver oaks due to rapid growth rate and less competitiveness with other crops (Okorio et al. 1994, Lott et al. 2000, Takaoka 2008). Besides, the land tenure system in Kodagu permits for easy felling of silver oaks for timber purpose and more importantly climbing support to pepper vines predominantly grown in coffee estates.

Land tenure systems in Kodagu and coffee cultivation practices

The higher percent of silver oaks were present in the redeemed land viz., about 33% and 62% in redeemed Arabica and Robusta estates respectively (Fig. 3). In other words, the tree rights conferred to redeemed (In case of redeemed land, the land owner holds tree rights. Whereas in case of unredeemed land the Government holds tree rights even though the land is owned by coffee grower) estates had prompted the growers to plant exotic silver oaks (*Grevillea robusta*) in place of indigenous native tree species. While the loss of shade tree canopy was observed more in redeemed land tenure (both Arabica and Robusta) thereby resulted in a major shift from traditional poly-cultures of native shade canopies to silver oak monoculture in coffee plantations.

Earlier, Arabica coffee was cultivated under the canopy of thick shade cover that comprised of

native tree species, however were now getting converted to Robusta that required sparse shade (Garcia et al. 2009). Nevertheless, our studies revealed that redeemed land comprised of lesser number of shade trees and a higher percent of silver oaks (Fig. 3). This, inturn indicated that redeemed land comprised of lower shade tree canopies and sparse shade cover were congenial for Robusta cultivation that required lower shade (40%) as against Arabica that required more shade (70%) as evident in unredeemed estates.

In contrast to the above results, the redeemed owners with available ownership of tree rights were allowed for felling of indigenous trees which were being replaced with silver oaks that had maintained a lower shade in their estates (about 40—60%), as required by Robusta. Moreover, the lower maintenance costs and ease of production of Robusta supported by the land tenure system (specifically in the redeemed land) had prompted the Arabica growers to shift towards Robusta cultivation which were more pronounced in the redeemed land.

Productivity of coffee in different types of shade tree systems

The functional form of the model is given as

$$Y = \alpha_0 + \beta_1 \text{ silver oak} + \beta_2 \text{ silver oak}^2 + \beta_3 \text{ indigenous trees} + \beta_4 \text{ dadaps} + \beta_5 d_1 + e \quad \text{..... (1)}$$

Where, Y is the productivity (kg/ha) of coffee, e is the unexplained error term, α_0 is constant or intercept, $d_1 = 1$, if land tenure is redeemed, 0 otherwise.

Though the fast growing exotic silver oak (*Grevillea robusta*) was preferred over the other native species (due to its high timber value), however had its adverse impact on productivity of Arabica variety of coffee (Table 2). For instance, Negawo and Beyene (2017) noted that the coffee bud emergence in the branches was adversely affected by the falling leaves of silver oaks that remained un-decomposed for several months for lower canopy shade, Dadap (*Erythrina* spp) are used. Moreover, the silver oaks at a lower canopy shade (15–20 feet) provided filtered shade, emit more radiation, temperature and reduce humidity within coffee plantations, that increased the incidence of White Stem Borer in Arabica (Murphy et al. 2008) and diseases like Coffee Leaf Rust and Coffee Thread Blight. This reduced tree canopy due to silver oaks had also resulted in increased temperature and reduced relative humidity, thereby making the environment uncongenial for cultivation of Arabica as this variety required higher shade cover (50–60%) and a lower temperature (15–24^{o}C).

In contrast to this, in case of Robusta variety of coffee, initially the number of silver oaks per ha had a positive impact (2.41) on productivity of Robusta. The inflection point with respect to silver oaks and productivity of Robusta was found to be 121 trees per ha. In other words, the productivity of Robusta variety of coffee increased with the number of silver oaks (upto 121 silver trees per ha).

Inflection point was estimated for silver oaks as both the co-efficient and it's square terms turned out to be significant.

$$\delta_y / \delta_{\text{silver}} \text{ oaks} = \beta_1 - \beta_2 * 2(\text{silver oak}) \text{ or, Age} = \beta_1 / 2\beta_2 = 2.41 / (2*0.01) = 121 \text{ silver oak trees per ha}$$

However, the productivity of Robusta was hampered (–0.01) in estates with more than 121 silver oak trees per ha. In other words, higher number of silver oaks in Robusta estates too proved to be detrimental for Robusta productivity. While the redeemed land tenure system comprised of higher number of silver oak trees that exhibited higher productivity in case of Robusta (Table 2).

The number of indigenous shade trees had positive influence on productivity of Arabica (0.04), in contrast to Robusta (–1.55). In case of Arabica, the coffee estates when provided with optimum shade, inturn could reduce the stress of coffee trees and buffer the high and low temperature by 5^o celcius. For instance, Barradas and Fanjul (1986) document that in Mexican coffee plantations, the optimum shade can reduce the maximum temperature by 5.4^o celcius, while Kirkpatrick (1935) noted that in East African plantations, the shade could reduce the temperature by 5–6^o celcius. However, the temperature in Kodagu varies between 16^o—39^o celcius, while the optimum temperature requirement for Arabica is about 15–25^o

celcius. Thus, the optimum indigenous shade trees in Arabica estates could reduce the temperature and provide ideal requirements for Arabica, to grow into healthy and vigorous plants, indicating positive influence of indigenous shade trees on productivity of Arabica.

It was noticed that, during the field visits that in few Robusta estates the coffee wilt disease (caused by *Gibberellaxyl arioides*) was higher in the shaded coffee plantation. Overall, the Robusta growers opinioned that lower shade from indigenous shade enhanced the productivity of Robusta, besides limited the spread of Shot Hole Borer (*Xylosandrus compactus*), that developed under higher shade, thereby the growers either removed excess shade trees or maintained a thin shade. Though, Shot Hole Borer was not a major problem, however could reduce the productivity by less than 5% (in estates comprising of higher shade). Nevertheless, the Robusta estates in Kodagu require a relatively sparse shading, are now opening up the shade and replacing with the silver oak, in order to attain higher productivity and prefer to cultivate almost sun grown coffee. Overall, the influence of shade trees on productivity of Robusta was negative (Table 2). Some authors documented lower yield associated with higher shade.

The dadaps (*Erythrina* spp.) were used as temporary shade at the lower canopy in case of Arabica, which influenced productivity of Arabica positively (0.71), however found to be insignificant in case of Robusta variety of coffee. The Arabica variety was cultivated under 2 tier system of shade, wherein the upper canopy comprised of permanent shade trees, while the lower canopy comprised of temporary dadaps (*Erythrina* spp.). These shade trees were regulated such that the Arabica trees were not exposed during the flight periods of coffee White Stem Borer (WSB) in Arabica, inturn reflected by higher productivity in case of Arabica.

Influence of shade trees on incidence of White Stem Borer (*Xylotrechus quadripes*) in Arabica

On the ecological front, the study analyses the impact of indigenous and exotic shade trees on the influence of coffee White Stem Borer (WSB) in Arabica. The coffee White Stem Borer (*Xylotrechus quadripes*), the most fatal pest of Indian Arabica was first reported in Mysore in 1838. The wide spread attack of this pest on Indian Arabica has resulted in subsequent uprooting of trees, reduction in plant population, decline in productivity and cumulative revenue losses to the growers (Venkatesha 2010). Furthermore, the reduced productivity of Arabica due to borer attack combined with higher risk and increasing cost of cultivation in Arabica has prompted the Arabica growers to shift towards lower quality and pest resistant Robusta variety of coffee.

Now, taking into account shade maintenance as one of the major management practices in coffee estates, the study attempts to understand the impact of shade trees (indigenous and silver oaks) on incidence of White Stem Borer in Arabica coffee. While, in India, the Arabica coffee is generally cultivated in two tier shade system, with permanent native shade trees on the upper tier and dadaps (*Erythrina* sp.) in the lower tier, while silver oak is a preferred shade (Murphy et al. 2008). The other independent variables included cost of pruning (Rs/ha), average annual rainfall (mm), age of coffee trees (years) and dummy on redeemed land.

The functional form of the model is given below.

$$\text{Ln (number of Arabica trees uprooted / ha)} = \alpha_0 + \beta_1 \text{Ln (indigenous trees / ha)} + \beta_2 \text{Ln (silver oaks trees / ha)} + \beta_3 \text{Ln (dadap trees/ha)} + \beta_4 \text{Ln (cost of pruning / ha)} + \beta_5 \text{Ln (average annual rainfall)} + \beta_6 \text{Ln (age of coffee trees)} + \beta_7 d_1 + e \quad \text{.....(1)}$$

The incidence of WSB reduced with the increase in number of indigenous shade trees and dadap trees and was found to be significant. Murphy et al. (2008) also noted that the coffee stem borer reduced with the density of dadap trees, inturn indicating that the canopy of dadaps was a major factor that determined the borer attack. The dadaps, as temporary shade were more common in Arabica estates, while the higher density of dadap trees resulted in higher amount of foliage, thereby providing the Arabica trees with more amount of shade that in some situations could reduce the incidence of borer attack (Murphy et al. 2008). While the number of exotic silver oaks though positively influenced the borer attack was found to

be in significant. However, Murphy, noted that the incidence of WSB increased with the increase in the density of exotic silver oaks. The incidence of White Stem Borer was found to be higher in case of redeemed land and increased with the pruning costs (Rs/ha). However, the average annual rainfall and age of coffee trees were found to be in significant in the study (Table 3).

Conclusion

The current policies do play a vital role. In case redeemed type of land tenure system existing in Kodagu, the exotics can be easily cut for timber without prior permission of government. However, this could influence the economic and ecological aspects of Arabica and Robusta varieties of coffee distinctly. Secondly, redeemed land tenure system in Kodagu also witnessed higher number of silver oak trees against the indigenous shade trees. The silver oak trees negatively influenced the productivity of Arabica coffee. Though the exotic silver oaks at initial numbers positively influenced productivity of Robusta, but the silver oaks above 121 trees per ha also had a negative influence on productivity of Robusta. Interestingly, the number of indigenous shade trees and dadap trees had pragmatic influence on productivity of Arabica alone, besides reducing the incidence of White Stem Borer in Arabica. Overall, it can be concluded that though the coffee agro-forestry system witnessed a rapid invasion of exotic silver oaks, with the gradual decline in the indigenous shade trees. However, our studies revealed that the indigenous shade trees had a major influence on productivity of coffee, particularly Arabica variety of coffee, besides reducing the incidence of coffee White Stem Borer.

Policy implications

Overall, the land tenure system in Kodagu as the norms and rules set by the Government or as an institution had a modest impact on the coffee agro-forestry system, productivity and on coffee production practices. However, the current land tenure system was very traditional by itself, which were formulated 500 years ago by the then ruled Haleri dynasty of Kodagu, latter consented by the British Government that persist even today in conflict with the interests of the land holders of Kodagu. Thus, in order to reconcile the traditional land tenure system as an institution with the modern system and to curb the destruction of indigenous shade trees, the Government need to re-look the tree standing rights in the private coffee plantations in Kodagu.

Over the recent years, coffee plantations are being grown under mono shade trees by replacing indigenous shade trees with exotic silver oaks, that witnessed higher incidence of White Stem Borer. In order to encourage the native shade tree species, the growers should be supplied with indigenous tree species, in tie up with the forest department.

Though the growers cultivate fast growing exotic silver oaks that could be harvested for timber purposes during financial crises, however has posed threat to native shade tree species and ecological aspects of coffee agro-forestry system. However, the coffee growers should be restricted for limited cultivation of silver oaks, particularly for redeemed land, that could allow the growers to benefit economically, with causing any ecological damage, to achieve a delicate balance between ecological sustainability and economic viability.

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