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Drivers of mistletoe (*Tapinanthus bangwensis*) density in cocoa (*Theobroma cacao*) agroforests in Ghana

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ABSTRACT

Mistletoes are parasitic flowering plants that attack plants like cocoa and kill branches distal to point of attachment. Consequently, cocoa farmers incorporate trees to provide shade to limit germination and establishment of *Tapinanthus bangwensis* mistletoe species, but without success. This study was conducted in South-Western Ghana to identify causal factors of mistletoe infestation using random forest (RF) regression. Spatial arrangement of cocoa trees was the most important factor explaining mistletoe density, which was significantly higher in farms planted at random than in rows. The results imply that planting cocoa trees in rows could mitigate mistletoe infestation of Ghana's cocoa agroforests.

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Tapinanthus bangwensis; cocoa agroforests; shade trees; smallholder farmers

1. Introduction

Mistletoes are parasitic flowering plants in the order *Santalales* that attach to the stem of other plants, primarily gymnosperms and angiosperms (Mathiasen et al. 2008). In Africa, they are commonly found in the family *Loranthaceae* and the genus *Tapinanthus*, and often attack cash crops, including cocoa. After establishment, the parasite can act as a sink for photosynthetic products manufactured by the trees, thereby killing branches distal to the point of attachment (Room 1971). Mistletoes reduce xylem water potentials and net photosynthesis of the trees, resulting in senescence, due to the high transpiration rates they cause (Knutson 1983; Stewart and Press 1990). Their infestation of cocoa trees also facilitates other fungal infestations (Room 1973; Opoku and Baah 2010).

Although 15 different species of mistletoes have been identified in Ghana (Appiah and Owusu, 1997), *Tapinanthus bangwensis* Engl. & K Krause (hereafter *T. bangwensis*) is the predominant mistletoe species in cocoa systems in Ghana, resulting in high yield losses (Figure 1). Opoku and Baah (2010) reported that about 14% of the total cocoa trees in Ghana were infested by *T. bangwensis*, which signals significant reductions in farmers' incomes. Consequently, incorporation of shade trees in cocoa systems in a form of cocoa agroforests has been the key mitigation measure against mistletoe infestation across cocoa-growing countries in the West African region (Opoku-Ameyaw et al. 2010; Smith et al. 2014; Asare and Raebild 2016). In these systems, farmers incorporate shade trees (approximately 15–18 trees/ha) into cocoa farms to provide 30%–40% canopy cover (CRIG 2010; Opoku-Ameyaw et al. 2010; Smith et al. 2014).

This strategy emanated from previous studies that found shade as a limiting factor in the germination and establishment of *T. bangwensis* (Room 1971, 1973). However, some of the shade trees have been implicated as hosts of *T. bangwensis* (Amoako-Attah et al. 2014; Akrofi and Acheampong 2016). The continual prevalence of *T. bangwensis* in cocoa agroforestry systems in Ghana, despite many years of shade trees management, suggests that other potentially important causal factors and their corresponding mitigation measures are yet unexplored.

Generally, the distribution of mistletoes coincides with the distribution of host trees, and these species are mostly found aggregated in patchy areas. For example, Arce-Acosta et al. (2016) reported that host availability and spatial arrangement are important factors that shape mistletoe distribution within a landscape. Spatial arrangements of cocoa trees could mediate mistletoes infestation indirectly by regulation of farm visibility, tree density (Verheij and Coronel 1992), shade coverage, and farm humidity. This could imply that cocoa trees within a certain distance of an infected tree are more likely to be infected than trees located further away. Yet, the potential effect of spatial arrangements of cocoa trees on mistletoes is still unexplored. Previous

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Figure 1. Mistletoe (*Tapinanthus. Bangwensis*; A) attached to the stem of a cocoa tree (B).

studies also showed that shade tree richness and density were important indices that explained parasitoid diversity in cacao agroforestry systems (Sperber et al. 2004; Daghela et al. 2013). While the current mitigation approach is centered primarily on the maintenance of the recommended shade tree density (i.e. number of trees per ha) with no emphasis on species diversity (i.e. species richness and evenness), it is unknown whether a diverse portfolio of shade tree species on cocoa farms have distinct influence on the prevalence of mistletoes. Additionally, the occurrence of mistletoes on host trees often correlates with individual tree characteristics such as age of the tree. Though mistletoes infest both young and old cocoa trees (Bunting 1926), it is still unclear whether cocoa trees become more susceptible to mistletoe infestation with age. Similarly, no known study has explored the roles of farm size and the variety of cocoa planted on mistletoe dynamics in the entire West African region. Meanwhile, Milne et al. (2015) highlighted the importance of these variables in their study of pest control in Europe.

Aside agro-ecological factors mentioned above, previous studies have confirmed the impact of farmers' demographic variables on farm management and productivity (Corner-Thomas et al. 2015; Hollinger and Staatz 2015; Osei et al. 2019). This is particularly relevant for Sub-Saharan Africa where agrosilvicultural activities are largely non-mechanized (Hollinger and Staatz 2015; Miller et al. 2017). Specifically, the gender of farmers, the age distribution, and their household sizes have implications on labour availability (Miller et al. 2017; Khoza et al. 2019) and the extent of use of farm equipment (Corner-Thomas et al. 2015). Nonetheless, the impact of farmers' demographic factors on the prevalence of mistletoe has not been investigated.

This study is the first to adopt a holistic approach, investigating potentially overlooked demographic and agro-ecological factors underlying mistletoe prevalence. For agro-ecological factors, the size of farm, the age of cocoa trees, the spatial arrangement of trees, the variety of cocoa planted, the diversity of shade trees, and the density of shade trees (trees/ha) were selected. Demographic variables included farmers' age, household size, and gender of household head. These variables were selected because they have impact on farm management, based on previous studies mentioned in the preceding paragraphs, but their impact on mistletoes distribution is yet unknown. Additional strength of this study is the possibility to rank these variables based on how important they are in explaining mistletoe density. The result will help in future attempt to build models of mistletoe density as a function of farm structural attributes and farmers' demographic variables.

2. Methodology

2.1. Study area

This study was conducted in Jomoro district within the Western Region of Ghana. The district lies between 4°80″ N and 50°21″ N and 2°35″ W and 3°07″ W (Ghana Statistical Service [GSS] 2014) and covers a total land area of 1,495 square km (GSS 2014). The vegetation of the district is highly diverse tropical forests, with some areas of fallow land and tree crops, and farms/plantations (Damnyag et al. 2013). The mean temperature in the district is 26 °C with relative humidity about 90% during the night, falling to about 75% when the temperature rises in the afternoon (GSS 2014). The population of the district was 150,107 in the 2010 census with 49.0% percent males and 51.0% females (GSS 2014). In the rural localities within the district, 60% of the households are into agriculture. The major crops grown in the area are cash crops like cocoa, coconut, oil palm, and a range of food crops amongst which cassava and maize are the most notable (GSS 2014). This district was selected for the study because it is located in the wet evergreen tropical forest region in Ghana responsible for about 50% of Ghana's total cocoa production and well noted for diverse indigenous shade tree species (Asare and Raebild 2016) and mistletoes (Room 1973).

2.2. Selection of farmers and data collection

Fifty farmers were recruited for this study, but 47 completed the full cycle of the study. The research team engaged five Community Extension Agents (CEAs) of the Ghana Cocoa Board (COCOBOD) to assist farmers to collate mistletoes occurrence on their farms throughout 2017 (January-December 2017) with data sheets. CEAs patrol cocoa farms regularly to offer technical advice to farmers and ensure their compliance with recommended best farming practices. Ten farms were assigned to each CEA to confirm mistletoe counts recorded by the farmers.

These assigned farms were already in the working jurisdictions of the CEAs to facilitate their regular visits to farms. The CEAs confirmed mistletoe records by verifying the cocoa trees from which mistletoes were identified and pruned. It is noteworthy that such identification and supervision of mistletoe pruning is a regular task of CEAs. Thus, contrasting farm management and structural attributes as well as farmers' characteristics underpin differences in mistletoe prevalence among farmers. Semi-structured questionnaires were also used to collect farmers' demographic variables and additional farm variables such as cocoa variety, cocoa age, and planting methods. Additional records on the selected farms were obtained (e.g. farm sizes, shade trees $\geq$12 m height) from the district's COCOBOD office.

2.3. Data analysis

Mistletoe density was computed in each farm as the mistletoe counts divided by farm size. Similarly, shade tree density was computed as the number of shade trees ($\geq$12 m height) divided by farm size. To characterize diversity of shade trees on each farm, shade trees identified and their individual abundance were used to calculate Simpson's S index (S) as follows:

$$S = \sum (n/N)^2$$

where n = abundance of each shade tree species; N = sum of abundances of all species.

The value of Simpson's S is decreased with increasing diversity. To reverse this phenomenon such that larger S values denotes more diverse shade trees, Simpson's S value was subtracted from 1 to get Simpson's diversity index (D, i.e. D = 1-S) before further analyses. Simpson diversity was selected based on contrasting farm sizes in this study.

After gathering data for the studied variables, general data inspection and exploratory analyses were performed to assess the structure of the dataset and identify any missing values. Principal Component Analysis (PCA) was performed with *FactoMineR* package (Le et al. 2008) to summarize and visualize how variables relate to one another. Subsequently, the Random Forest (RF) regression model was used to determine important explanatory variables, which explain mistletoe density (response variable) with *randomForest* R package (Liaw and Wiener 2002). RF modelling is a non-parametric machine-learning method that requires no distributional or functional assumptions on covariate's relation to the response (Breiman 2001). This implies that compliance with parametric assumptions, such as normality of residuals and homoscedasticity, is not required for the RF regression (Breiman 2001). More importantly, multicollinearity among explanatory variables does not affect the RF regression (Breiman 2001). RF also reveals complex nonlinear relationships that may elude conventional statistical approaches (Cutler et al. 2007). Moreover, it allows flexibility in fitting regression models to exploratory datasets for which prior knowledge of the nature of the relationship between explanatory variables and the response variable (e.g. linear, nonlinear) is unknown (Cutler et al. 2007). In order to avoid overfitting often associated with machine learning techniques, cross validation with subsets of the data was undertaken to validate the model's performance. The expression below was used for the RF regression.

$$\begin{aligned}\text{Mistletoe density} &= \text{cocoa age} + \text{farm size} \\ &+ \text{shade diversity} + \text{shade density} + \text{cocoa arrangement} \\ &+ \text{cocoa variety} + \text{farmer age} + \text{household size} \\ &+ \text{gender}\end{aligned}$$

In order to identify and rank important explanatory variables for mistletoe density, the percentage increase in mean squared error (% MSE) of the RF model was computed after permuting values of each variable (Liaw and Wiener 2002). Variables with high % MSE are considered important because misspecification or exclusion of such variables from the model detracts from the predictive accuracy of the RF. Following Ishwaran et al. (2010), minimal depths of the RF model were computed to obtain an average threshold, which separates explanatory variables into more and less important ones. Minimal depth approach in the RF assumes that variables with high impact on the prediction are those that most partition large samples of the population (Ishwaran et al. 2010).

3. Results

The majority (57.40%) of the studied farms had cocoa trees planted randomly. The average age of cocoa trees in the farms studied was 17.9 (SD = 6.9) years with mean shade tree density of 14.31

Table 1. Descriptive summary of variable used in this study.

Variable	Description	Min	Max	Mean	SD
Farmer age	Age of farmer (years)	30	73	50.8	10.2
Household size	Members' ≥18 years in a household	3	10	6.5	1.6
Farm size	Size of cocoa farm (hectares, ha)	2	10.6	6.1	2.2
Cocoa age	Age of cocoa trees (years)	4	30	17.9	6.9
Shade density	Shade trees (≥12 m height) count/farm size	0.0	25.0	14.3	6.4
Shade diversity	1-Simpson's S index of shade trees per farm	0.0	0.70	0.3	0.1
Mistletoe density	Number of mistletoes/farm size	1.0	112.0	42.7	35.0
Variety	Variety of cocoa planted by farmers		Amazonia = 19; Hybrid = 28		
Gender	Gender of head of a household		Male = 44; Female = 3		
Cocoa arrangement	Spatial arrangement of cocoa trees		Rows = 20; Random = 27		

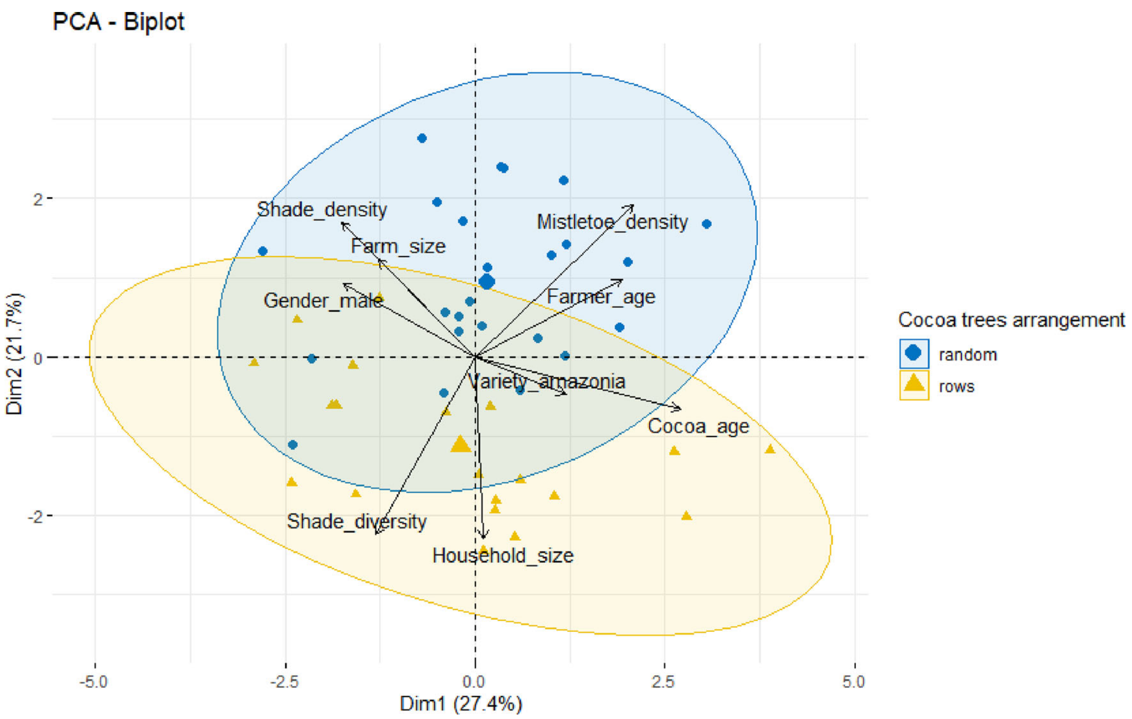

Figure 2. Principal Component Analysis of variables used in this study. The dots are individual cocoa farms. The two ellipses categorize farms into those planted in rows and at random.

(SD = 6.4) tees/ha. The majority of the farmers were males and the mean household size was six. The remaining descriptive summary of the variables used for this study is reported in Table 1.

From the PCA, it was observed that the first principal component was positively related to cocoa age, mistletoe density, and farmers' age, while negatively related to shade density and male farmers (Figure 2). The second principal component is driven by household size, shade tree diversity, mistletoe density, and shade tree density. The PCA showed that male farmers are more likely to have relatively young and large farms with high density of shade trees. It further showed that farmers with large household sizes are likely to have species diverse shade trees on their farms. As generally expected, farmers' age was related to cocoa age (Figure 2).

The RF regression technique explained 66.9% of variability in mistletoe density (Table 2). The predicted mistletoe density by the RF model highly correlates with the observed values (Figure A1). These values indicate a high model performance. In descending order of importance per % MSE metric, cocoa arrangement, farmers' age, cocoa age, shade diversity, and shade density were the most important variables explaining mistletoe density (Table 2). The top four important variables by %MSE was in agreement with that of minimal depth method (Table 2). This finding suggests that removing any

Table 2. Summary of variable importance from the random forest (RF) analyses.

Variables	% MSE	Depth
Cocoa arrangement	15.8	2.0*
Farmer age	13.7	2.1*
Cocoa age	10.1	2.4*
Shade trees diversity	7.9	2.4*
Shade trees density	7.0	3.0
Household size	6.9	2.8
Gender of household head	6.1	3.5
Farm size	5.7	2.2*
Cocoa variety	−1.9	3.8

% MSE of a variable shows the percent increase in the mean squared error (MSE) of the model after permuting values of that variable. More important variables have high % MSE values. The minimal depth (*) indicates minimal depth values lower than the average minimal depth over all variables (i.e. 2.7). The RF model explained 66.9% variability in mistletoe density.

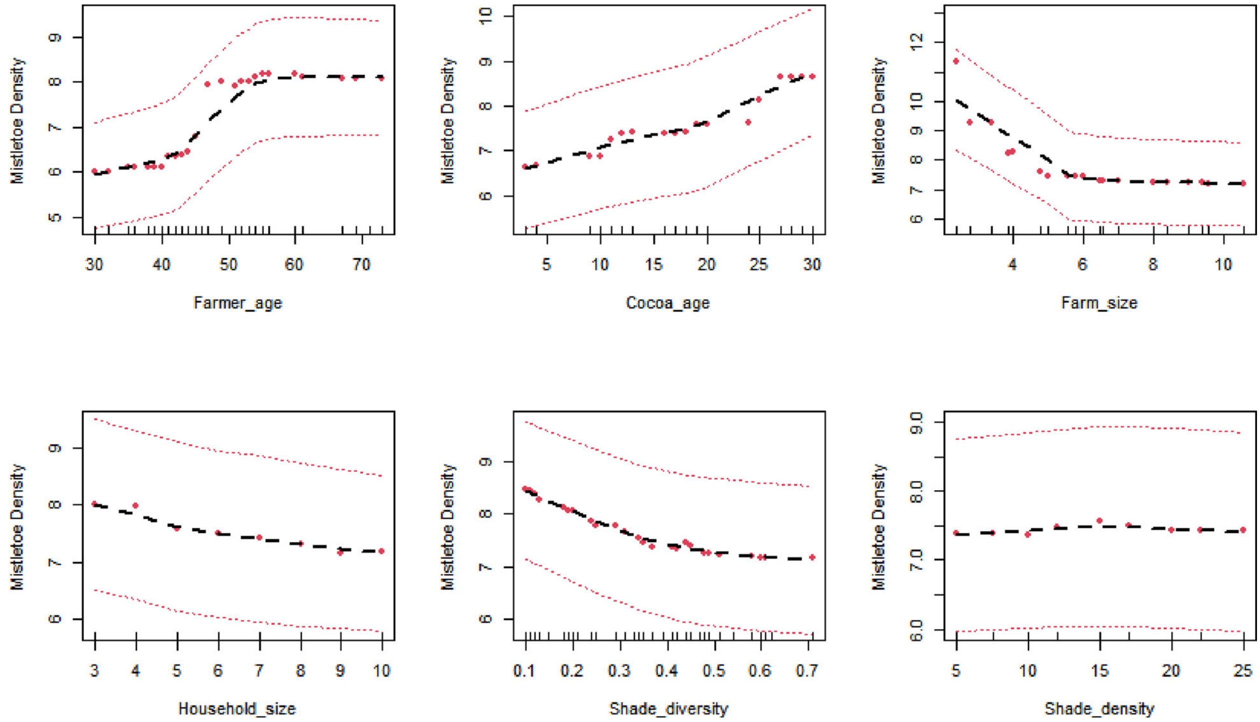

Figure 3. Random forest partial dependence of mistletoe density on farmers' age, cocoa age, farm size, shade diversity, shade density and household size. Values shown are predicted mistletoe densities as a function of each variable when all other variables are held at their mean values.

of the top ranking variables substantially weaken the predictive power of the model, in correspondence with the rank of the variables.

The RF partial dependence plots showed relationships between mistletoe density and all continuous explanatory variables (Figure 3). Mistletoe density increased with farmers' age, decreased considerably with increasing shade tree diversity, and increased with cocoa age (Figure 3). Further investigations on spatial arrangements of cocoa trees revealed that mistletoe density was significantly higher in cocoa farms planted at random than those in rows (Figure 2; Figure A2).

4. Discussion

In the present study, farm structural attributes and farmers' demographic variables that explain mistletoe density in cocoa agroforestry systems were examined. The results suggest that cocoa arrangement, farmers' age, cocoa age, shade diversity, and shade density are important variables explaining mistletoe density in cocoa farms in South-Western Ghana.

Spatial arrangement of cocoa trees was the most important factor explaining mistletoe density, which was significantly higher in cocoa farms planted at random than those in rows. A plausible reason could be the enhanced visibility within the row planting farming systems. Verheij and Coronel (1992), for example, indicated that spatial arrangements of host trees could mediate mistletoes infestation indirectly by regulation of farm visibility. In the case of the present study, mistletoe disseminating agents such as birds could avoid such visible row planting systems as a predator avoidance strategy (Yuan et al. 2018), resulting in less dispersion and spread of the parasite. Also, cocoa planted randomly have higher densities than those planted in rows. On average, cocoa planted in rows with spacing of 3 m x 3 m has an estimated density of 1111 trees/ha while the random system could have between 2000-3000 trees/ha. As a result, random systems could have more cocoa trees closer to one another. Hence, infected trees are likely to have many trees within the range of infection. Host tree density, in this case the density of cocoa trees, known to influence the frequency and distribution of mistletoe in farms (Arce-Acosta et al. 2016), could have contributed to the higher density of the parasite in the random system than the row system.

Farmers' age was the second most important factor of mistletoe density. The predicted mistletoe density increased with farmers' age, but leveled-off at ~55 years. The recommended physical pruning of mistletoe infested cocoa branches as a control measure (Room 1973; Lass 1985; CRIG 2010) is a physically demanding farming activity that is impacted by household labour. Per theoretical expectations, physical capabilities of farmers to undertake pruning and other mistletoe-prevention activities will decline with age, especially when farmers' age does not necessarily correlate with household size (Figure 2). Agrosilvicultural practices in cocoa agroforestry systems in West Africa are usually non-mechanized and labour-intensive, and depend greatly on household demographics for optimal productivity (Fonta and Ayuk 2013; Hollinger and Staatz 2015; Miller et al. 2017). In New Zealand, Corner-Thomas et al. (2015) found that farmers' age was negatively related with the use of farm equipment, in that older farmers were less likely to use an equipment than younger farmers. As farmers' age highly conflates with farming experience, the level-off at ~55 years could be due to enhanced capacities of farmers acquired via decades of mistletoe control and general farm management.

The age of cocoa trees was the third most important factor, with predicted mistletoe density increasing with cocoa age. Tree size, which increases with cocoa age, is an important factor in attracting mistletoe bird dispersers (Thébaud et al. 1992; Overton 1994). Thomson and Mahall (1983) have attributed the positive relationship mistletoe infections and tree size to the quality of large old trees as perches for birds. Secondly, old cocoa farms could have the structural complexity ideal for mistletoe disseminating birds, which could increase mistletoe infestations (Bunting 1926).

Diversity of shade trees was the fourth most important factor. The predicted mistletoe density decreased substantially with increasing shade tree diversity. Higher tree species diversity increases the chances of having shade trees with distinctive branching architecture and bigger crown area that could create complex canopy cover and shade on the farm (Asare and Raebild 2016; Braga et al. 2019) as mistletoes germinate and grow best in warm and sunny locations (Gill and Hawksworth 1961). Consequently, cocoa farms with diverse shade trees could have less mistletoe density than farms with limited shade tree diversity occasioned by possible canopy complementarity. Because some shade trees act as hosts to mistletoes, increasing the portfolio of tree species on cocoa farms could limit the host range of mistletoes (Lavorel et al. 1999) through a "dilution effect" (Civitello 2015). The "dilution effect" implies that where species vary in susceptibility to an infection, higher diversity often leads to lower infection prevalence in hosts (Civitello 2015).

5. Conclusion and limitations

This study examined the importance of farm structural attributes and farmers' demographic variables in explaining mistletoe density in cocoa agroforestry systems in the Western Region of Ghana. Findings have implications for the management of cocoa agroforestry systems as far as mistletoe control is concerned. The study suggests an emphasis on cocoa arrangement, farmers' age, cocoa age, and shade diversity in mistletoe control. Additionally, COCOBOD should encourage row planting of cocoa trees to control mistletoes. Furthermore, programs often implemented by COCOBOD to assist farmers in the control mistletoes should be farmer specific, taking cognizance of their ages and household sizes. This will ensure that old farmers and those with small household sizes are prioritized in assistive programs. The current study was conducted in Jomoro district within the Western Region of Ghana, which is just one out of the cocoa producing districts. As already established by previous studies, parasitic plants are influenced by several other environmental factors apart from those tested here. Although findings of this study could be generalized to a great extent, it will be necessary for other similar studies in other parts of the country to help fully understand the patterns of mistletoe distribution observed in the present study.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

Data available on request due to privacy/ethical restrictions.

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Appendices

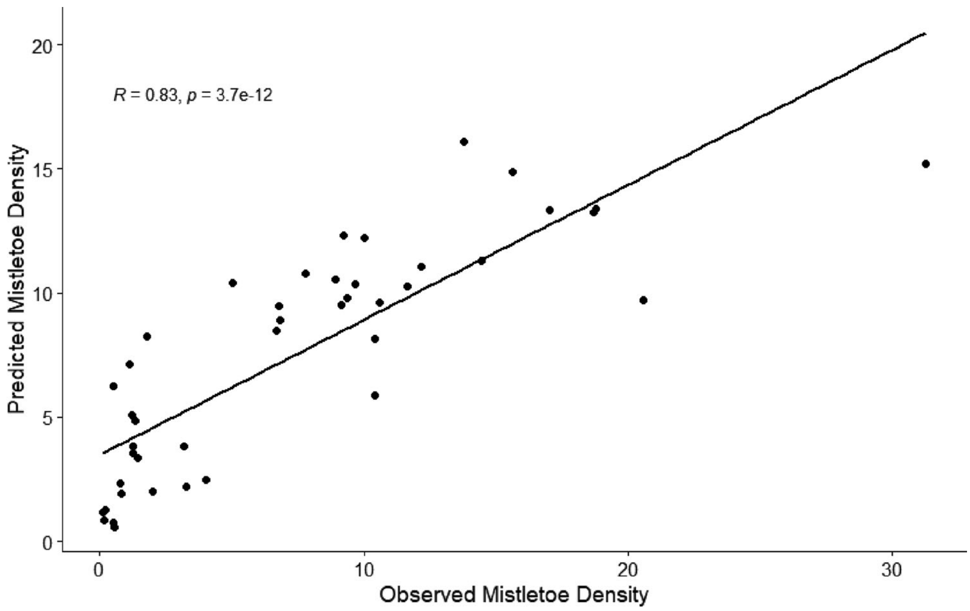

Figure A1. Observed mistletoe density versus predicted mistletoe density by the random forest model.

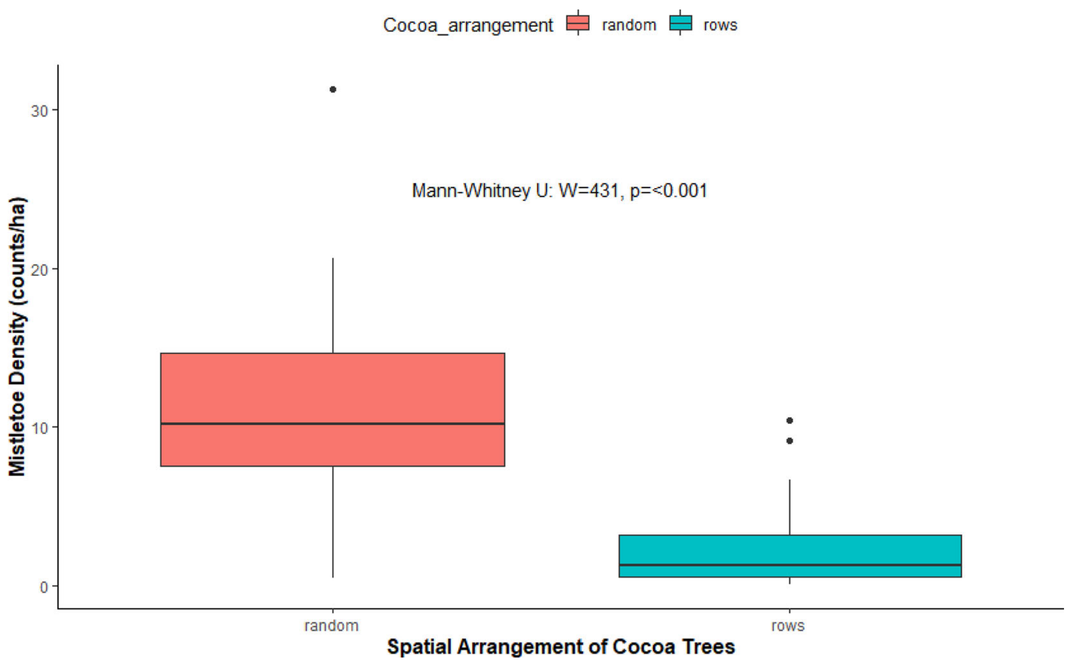

Figure A2. Comparison of mistletoe density between cocoa farms planted at random and in rows. Difference is significant at 95% confidence level.