Agronomic performance and productivity of Arabica coffee intercropped with timber species[1]

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ABSTRACT

The insertion of the tree component in coffee production is a strategy from an economic and environmental perspective. Thus, the objective of this study was to evaluate the temporal influence on the agronomic and productive performance of the coffee crop under the interference of different tree species as a function of spacing. The experiment was set in the municipality of Santo Antônio de Amparo-MG, in 2012, and conducted in a randomized block design with four replications. The treatments were: cultivar 'Catuai Vermelho IAC 99' in monoculture (3.40 m x 0.65 m) and intercropped with African mahogany, teak and pink cedar, in two spacings (9 x 13.6 m and 18 x 13.6 m), in coffee rows. Three coffee rows were fixed between rows, totaling 13.6 m. The following variables were evaluated: height (m), stem diameter (cm), crown diameter (m), productivity (bags ha^{-1}) and yield (l/sc) for coffee. From the evaluations, there is a significant effect of height, productivity and yield for the coffee crop. The system intercropped with tree species did not influence coffee productivity and yield until the 3rd harvest and, for the 5th harvest, intercropping with mahogany favored productivity, although the accumulated productivity did not show any treatment effect.

Keywords: *Acrocarpus fraxinifolius; Coffea arabica; Khayana ivorensis*; *Tectona grandis*; agroforestry system.

INTRODUCTION

Coffee is considered one of the main crops in the country, and has the potential to be associated with the forestry sector. The cultivation of noble tree species has been highlighted in the forest scope, since they can provide wood of excellent quality with high added value (IBÁ, 2018), making it increasingly viable, given the reduction in the areas of exploitation of wood from native forests.

Coffee plants in Brazil are mostly grown in monoculture, due to the ease of managing and implementing mechanized planting techniques (Camargo, 2010). However, coffee plantations in monoculture expose the coffee crop to climatic risks such as frost (Waller *et al.*, 2007), in addition to the plants becoming vulnerable to the wind (Parra & Reis, 2013), to excessive temperatures and lower water availability. According to Vieira *et al.* (2015), the benefits of shading in coffee crops in situations of extreme environmental conditions are evident.

In this context, one of the viable solutions would be the insertion of the tree component, favorably contributing to agriculture and livestock, minimizing the impacts caused

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by monoculture (Miccolis *et al.*, 2016), increasing the versatility of agriculture, in addition to enabling productive diversification (Schembergue *et al.*, 2017), generating extra income for the producer.

The cultivation system plays a strategic role, contributing to environmental and economic sustainability. Recently, this type of cultivation has generated a new commitment in the market, due to environmental concerns and the preservation of native forests (Saath & Fachinello, 2018).

For commercial exploitation and in order to avoid errors, it is necessary to plan all phases, especially those related to crop implementation and formation. An error in this period can seriously compromise crop longevity and productivity (Dardengo *et al.*, 2013).

Thus, the species of the selected tree or its spatial arrangements in intercropped systems result in different changes in the microclimate (Araújo *et al.*, 2015), which can be promising for coffee productivity.

Therefore, the objective of this study was to evaluate the temporal influence of agronomic and productive performance of the coffee crop, under the interference of different tree species, as a function of spacing.

MATERIAL AND METHODS

The experiment was set in November 2012, on Fazenda da Lagoa, owned by the Neumann Kaffee Gruppe (NKG), located in the municipality of Santo Antônio do Amparo, Minas Gerais (MG), a coffee producing region in Southern Minas Gerais, whose coordinates are 20º 54' 58.1"S and 44º 511 13.7" W, altitude of 1.089 m, average temperature of 19.8 ºC, 1670 mm/year rainfall and, according to Köppen-Geiger, the climate classification is classified as Cwa (subtropical highland climate), with dry winter and hot summer. The soils of the area are classified as Latossolos (Oxisols), according to the Brazilian Soil Classification System (Santos *et al.*, 2018). In the years 2015, 2016, 2017 and 2018, productivity and agronomic performance were evaluated, referring to the second, third, fourth and fifth crops, respectively.

The experiment was carried out using a randomized block design (RBD), consisting of four replications in schemes of plots subdivided over time. The experiment consisted of seven treatments: Monoculture coffee crop (Mono); coffee plants intercropped with African mahogany at 9 x 13.6 m (MoE1) spacing; coffee plants intercropped with African mahogany at 18 x 13.6 m (MoE2) spacing; coffee crop intercropped with teak at 9 x 13.6 m (TeE1) spacing; coffee crop intercropped with teak at 18 x 13.6 m (TeE2) spacing; coffee plants intercropped with pink cedar at 9 x 13.6 m (AcE1) spacing; and coffee plants intercropped with pink cedar at 18 x 13.6 m (AcE2) spacing.

The three wood plant species were planted in the coffee rows simultaneously with the plantation of 'Catuaí Vermelho IAC 99' arabica coffee at a spacing of 3.40 m between rows per 0.65 m between plants. Three coffee rows interspersed among the tree species were fixed in the spacing between rows in a total of 13.6 m between the wooded rows.

To obtain the canopy diameter of wood species, the radius of the distance of the canopy projection on the ground was considered in relation to the tree shaft, and was measured using a ruler, in meters (m).

The means of treatments were considered for the values of canopy diameter of wood species. For the year 2017, MoE1 (2.30 m), MoE2 (2.30 m), TeE1 (1.70 m), TeE2 (2.33 m), AcE1 (4.67 m), AcE2 (5.20 m) and, in the year 2018: MoE1 (2.50 m), MoE2 (2.63 m), TeE1 (2.31 m), TeE2 (2.93 m), AcE1 (6.40 m), AcE2 (7.40 m).

Harvest was evaluated from the total detachment of fruits per plot, evaluating six plants in each plot; in other words, three plants located at 0.65, 1.30 and 1.95m to the left and three plants located at 0.65, 1.30 and 1.95m to the right of the wood species in the planting row. Subsequently, the fruits harvested from the six plants were mixed and a sampling of 4 L was taken per experimental plot. Such samplings were exposed to the sun until reaching the adequate moisture content to proceed to their processing (between 11 and 12%) with the constant inversion, so the drying process would homogenously take place.

After coffee processing, the samples were weighed; productivity conversion was then calculated (sacks ha^{-1}), besides yield (liters of harvested coffee/60 kg bag of processed coffee).

For agronomic performance analysis, the following characteristics were evaluated: height (m), stem diameter (cm), canopy diameter (m).

The values of agronomic performance and productivity were submitted to analysis of variance using the statistical software SISVAR 4.3 (Ferreira, 2011). The mean values were compared by the Scott-Knott test, at 5% significance. The graphics illustrating productivity and yield were plotted using the software Microsoft® Office Excel©.

RESULTS AND DISCUSSION

In view of the results of increment in height, stem diameter and crown diameter of coffee plants intercropped with timber species and in monoculture, the difference was observed for the height of the coffee tree when intercropped (Table 1).

Table 1: Analysis of height growth (m), stem diameter (cm) and crown diameter (m) of coffee plants intercropped with: MoE1 = African mahogany (9 x 13.6m); MoE2 = African mahogany (18 x 13.6m); TeE1 = teak (9 x 13.6m); TeE2 = teak (18 x 13.6m); AcE1 = pink cedar (9 x 13.6m); AcE2 = pink cedar (18 x 13.6m); Mono = coffee crop in monoculture

	Coffee growth											
	Height (m)				Stem diameter (cm)				Crown diameter (m)			
Treatments	**2015**	**2016**	**2017**	**2018**	**2015**	**2016**	**2017**	**2018**	**2015**	**2016**	**2017**	**2018**
MoE1	1.21	1.53	1.84	1.98	3.35	4.06	4.68	5.64	1.42	1.65	1.85	2.09
	Ad	Ac	Ab	Ba	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa
MoE2	1.20	1.44	1.81	1.99	3.24	4.27	4.50	5.55	1.34	1.52	1.85	2.07
	Ad	Bc	Ab	Ba	Ac	Ab	Ab	Aa	Ad	Ac	Ab	Aa
TeE1	1.24	1.52	1.82	1.96	3.55	4.28	4.63	5.71	1.39	1.52	1.80	2.05
	Ad	Ac	Ab	Ba	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa
TeE2	1.16	1.52	1.77	1.92	3.26	4.09	4.49	5.28	1.36	1.65	1.93	2.13
	Ad	Ac	Ab	Ba	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa
AcE1	1.20	1.46	1.90	2.09	3.38	4.04	4.66	5.60	1.33	1.55	1.86	2.14
	Ad	Bc	Ab	Aa	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa
AcE2	1.14	1.62	1.87	1.97	3.37	4.45	4.46	5.63	1.31	1.65	1.92	2.17
	Ac	Ab	Aa	Ba	Ac	Ab	Ab	Aa	Ad	Ac	Ab	Aa
Mono	1.21	1.56	1.92	2.08	3.39	4.22	4.67	5.60	1.42	1.65	1.88	2.12
	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa	Ad	Ac	Ab	Aa
Mean	1.64				4.43				1.73			
CV 1 %	5.74				5.38				6.39			
CV 2 %	4.71				8.11				3.00			
CV 3 %	4.46				5.44				3.96			

Means followed by the same uppercase letter in the column and lowercase letter in the line did not show significant differences, by the Scott Knott test, at 5% significance.

It is observed that coffee height was the only variable altered in response to treatments in the 4 years evaluated. In high biennial years of coffee, there was a differentiation in treatments, that is, in 2016, coffee intercropped with MoE1, TeE1, TeE2, AcE2 had the highest heights and, in 2018, AcE1; the latter was not differentiated from the monoculture. Therefore, it is possible to state the non-occurrence of competition between plants, since the height of the coffee tree does not differ from the monoculture.

In view of the above, Dias *et al.* (2007), found that when the vegetative growth of coffee was not reduced in relation to monoculture, there was possibly no competition, due to the high potential for extracting water and nutrients from the soil, that is, the existence of dynamic interactions between the species. According to Godoy *et al.* (2017), when there is competition between plants for light, it favors plant growth in height in comparison to monoculture.

According to Miccolis *et al.* (2016), when the spacings are properly combined, space occupation is optimized and the best use of resources (water, nutrients and symbiotic organisms, such as fungi and bacteria) becomes viable, which would be more possible for the success of the coffee crop in the establishment of SAFs.

In 2018, the highest height was for coffee intercropped with pink cedar in the short spacing (9 x 13.6 m), equaling monoculture. In the other treatments, the coffee crop showed height restrictions. Corroborating this study, Jaramillo-Botero *et al.* (2010), observed the lowest vegetative coffee growth in the year of high bienniality. Rodríguez- Lopéz *et al.* (2014), state that differences in growth availability can

cause physiological changes in the growth of coffee plants.

Given the above, it is not known for sure whether the effect on coffee is due to shading or soil resources, although there was no interference in coffee productivity in 2018 which, by the way, obtained excellent productivity when in the presence of mahogany (Table 2).

Table 2: Productivity (sc/ha) of coffee intercropped with: MoE1 = African mahogany (9 x 13.6m); MoE2 = African mahogany (18 x 13.6m); TeE1 = teak (9 x 13.6m); TeE2 = teak (18 x 13.6 m); AcE1 = pink cedar (9 x 13.6m); AcE2 = pink cedar (18 x 13.6m); Mono = coffee crop in monoculture, in 2015, 2016, 2017, 2018 and accumulated

Treatments	Productivity (sc/ha)				
	2015	2016	2017	2018	Accumulated^{ns*}
MoE1	33.50 Ab	55.46 Ab	44.21 Ab	109.47 Aa	242,64
MoE2	27.65 Ac	57.10 Ab	24.34 Bc	125.34 Aa	234,43
TeE1	25.37 Ac	50.90 Ab	26.91 Bc	98.22 Ba	201,40
TeE2	24.35 Ac	59.43 Ab	30.43 Bc	95.57 Ba	209.78
AcE1	17.72 Ac	53.13 Ab	44.41 Ab	87.73 Ba	202.99
AcE2	30.60 Ab	57.21 Ab	44.21 Ab	93.87 Ba	225.89
Monoculture	29.70 Ac	52.63 Ab	58.25 Ab	83.19 Ba	223.77
Mean	26.98	55.12	38.96	99.05	220.13
CV1 (%)		27.40			
CV2 (%)		31.26			13.69
CV3 (%)		25.28			

Means followed by the same uppercase letter in the column and lowercase letter in the line did not show significant differences, by the Scott Knott test, at 5% significance. ns*: not significant.

Regarding coffee productivity, there was no significant difference for the years 2015 and 2016, with significance appearing in the years 2017 and 2018, although the accumulated productivity did not show an effect of the treatments (Table 2). From the results, it can be observed that, in the first biennium, there was no significant difference between treatments.

However, from the second biennium referring to the 4th and 5th harvest, the treatments already influenced the coffee tree. In 2017, a year of low bienniality, coffee productivity decreased when combined with MoE2, TeE1 and TeE2.

Coffee intercropped, mainly with teak, showed a relationship between growth and productivity, that is, in the presence of teak, regardless of spacing, coffee was the one that invested the most in height growth in 2016 (Table 1), providing a decrease in productivity in the following year of 2017. INCAPER (2018) mention that the growth of trees directly interfered in the productivity of the coffee tree in the 4 years of study.

This fact shows the low productivity in 2017, due to the decrease in reserves that were spent in the previous year for the vegetative development of height. Jaramillo-Botero *et al.* (2010) state the existing correlation between lower productivity and higher vegetative growth. According to Sakai *et al.* (2015), periods of low coffee productivity are linked to the amount of low energy for fruiting and the supply is directed to growth. In this context, Assis *et al.* (2014) also state that productivity is linked to the height phenotype, especially in the first harvests.

Regarding the shading of trees on the coffee crop, Matta & Rodríguez (2007) explain that, for coffee plants grown in shaded environments, as the shading level increases, there is a greater stimulus to the emission of vegetative buds and the reduction in the formation of flower buds, which could also have contributed to the low coffee productivity, especially when intercropped with teak, regardless of spacing, in the following year of 2017 (Table 2).

Coffee may have been sensitized when intercropped with teak, taking into account the characteristics of the tree leaf, resulting in a greater contact surface over the coffee tree, that is, greater shade; it may also be assigned to allelopathic factors, one more that would contribute to lower coffee productivity in 2017.

It is also important to mention that, among the years studied, 2017 was the one with the lowest rainfall (1,683 mm) among the other years of study: 2015 (1,794 mm), 2016 (2,177 mm) and 2018 (1,913 mm), being one more factor that would favor lower productivity in 2017.

Therefore, the choice of the species to be cultivated must be fundamental, preventing incompatibility and avoiding competition between plants.

In 2018, regarding the 5th harvest, the intercropping system starts to stand out on coffee productivity of monoculture, especially when it comes to mahogany, favoring the coffee crop in the two different spacings used.

According to INCAPER (2018), coffee intercropped with mahogany at a spacing of 12 m x 9 m in a 2-year study (2015-2016) shows a promising system for coffee and mahogany.

The selected tree species, together with its spacing, will result in a differentiated microclimate (Araújo *et al*., 2015), generated by the differentiation of leaf structures in the tree canopy, reflecting on productivity. As in the work of Freitas *et al.* (2020), the coffee tree in intercrop with the correct management of the trees, as for example, the intercrop with the mahogany, presented superior productivity when compared to the coffee tree in monoculture.

On the other hand, it is observed that the accumulated (Table 2) harvests did not differ in terms of treatments, which would be a desirable result for producers, that is, there would be no losses in coffee productivity when in the presence of trees, in relation to monoculture; it is also possible to observe the tendency of greater productivity when in the presence of mahogany.

Figure 1 shows the behavior of productivity over the years 2015, 2016, 2017 and 2018. With the productivity data, there is a marked trend in coffee bienniality, even with the crops still young. It is also possible to observe that productivity increased over the years.

It is interesting to observe the trends of the coffee crop according to the tree spacing adopted. The coffee crop, in association with MoE1, tends to produce more in low bienniality compared to MoE2, which produces more in high years. With teak, the coffee crop did not present a predictable behavior. On the other hand, when intercropped with AcE2, coffee seems to have a tendency to produce more in relation to AcE1, a fact expected by the size of the plants and the shading provided.

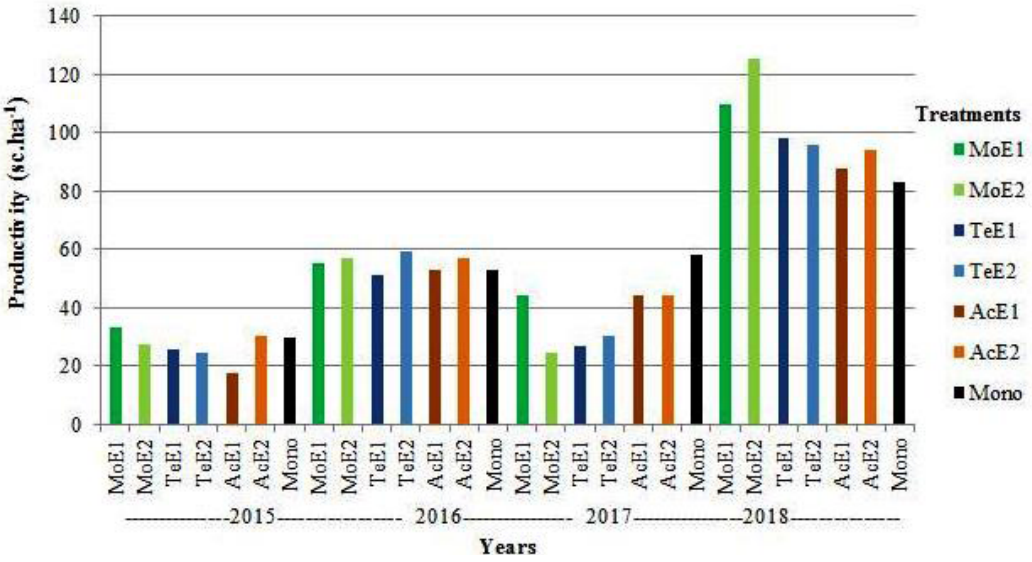

Figure 1: Productivity (sc.ha^{-1}) of coffee intercropped with: MoE1 = African mahogany (9 x 13.6m); MoE2 = African mahogany (18 x 13.6m); TeE1 = teak (9 x 13.6m); TeE2 = teak (18 x 13.6m); AcE1 = pink cedar (9 x 13.6m); AcE2 = pink cedar (18 x 13.6m); Mono = coffee crop in monoculture, in 2015, 2016, 2017 and 2018.

This comparative effect helps understand the reaction and the performance of the coffee crop in different situations, adding information of choice to the producer.

For yield, the results below indicate that, in the first biennium, there was no difference in treatments (Table 3), with the year 2015 referring to the 2nd crop and the lowest yield values in relation to the years 2016, 2017 and 2018, that is, greater quantities of harvested fruit were necessary to complete a 60 kg bag of processed coffee.

It is observed that, in 2017 and 2018, the behavior of yield was similar to productivity, that is, coffee intercropped with MoE2, TeE1 and TeE2 remains with the lowest yields, that is, it needs a greater amount of harvested fruit to reach the 60 kg bag of processed coffee. However, in 2018, in the presence of mahogany, coffee had a higher yield in a positive way.

Table 3: Yield (l/sc) of coffee intercropped with: MoE1 = African mahogany (9 x 13.6m); MoE2 = African mahogany (18 x 13.6m); TeE1 = teak (9 x 13.6m); TeE2 = teak (18 x 13.6m); AcE1 = pink cedar (9 x 13.6m); AcE2 = pink cedar (18 x 13.6m); Mono = coffee crop in monoculture, in 2015, 2016, 2017 and 2018

Treatments	Yield (l/sc)			
	2015	2016	2017	2018
MoE1	788.70 Ab	562.26 Ab	440.67 Ab	355.56 Aa
MoE2	873.00 Ac	565.52 Ab	503.89 Bc	340.73 Aa
TeE1	664.44 Ac	623.47 Ab	443.31 Bc	378.78 Ba
TeE2	704.57 Ac	494.30 Ab	446.22 Bc	378.25 Ba
AcE1	740.03 Ac	528.78 Ab	401.48 Ab	357.17 Ba
AcE2	803.56 Ab	531.25 Ab	385.95 Ab	371.76 Ba
Monoculture	787.09 Ac	575.92 Ab	435.13 Ab	411.89 Ba
Mean	765.91	554.5	436.66	370.59
CV1 (%)	8.61			
CV2 (%)	7.34			
CV3 (%)	8.92			

Means followed by the same uppercase letter in the column and lowercase letter in the line did not show significant differences, by the Scott Knott test, at 5% significance.

This fact, which was negative in 2017, may be the result of competition, mainly for water, leading to poor bean formation. In addition, it can be attributed to the local microclimate generated by the trees, which can directly affect the development of the husk (exocarp) of the coffee fruits, since yield is calculated by the ratio of the weight of harvested coffee and the weight of processed coffee.

It is also possible to say that coffee intercropped with most shading species, provided by the greater growth of the crown, favors larger fruits and higher yields, although crowns with excessive shading can harm fruit formation, decreasing yield (Freitas *et al*., 2020).

Intercropping has gained attention due to the increase of the quality of ripe "cherry" fruit of coffee trees (Prado *et al.*, 2018). The microclimate formed by moderate shading leads to a delay of fruit ripening, resulting in a longer period of development that results in larger beans (Bote & Vos, 2017).

In the study of Figueiredo *et al.* (2015), higher yields of coffee beans were found when intercropped with cedar, "embaúba" and "andiroba". Moreira *et al.* (2018) observed higher coffee yields when intercropped with "macaúba" with about 4 m of distance between the rows of these crops in the year of strong drought in the Zona da Mata Mineira in 2014.

Thus, it is interesting to point out that 2014 (summer) was the year of alarming drought conditions (Santini, 2020). Therefore, the presence of certain trees with adequate spacing and management would be one of the factors contributing to favor coffee yield when combined, due to the microclimate and soil moisture generated by timber species.

Figure 2 shows the yield over the years 2015, 2016, 2017 and 2018. There is a decreasing trend in yield over the years, that is, in the first harvests, bean yield is lower, that is, more liters of harvested coffee are needed to reach the 60 kg bag of processed coffee.

It is relevant to correlate this yield graph (Figure 2) with the productivity graph (Figure 1) once, in general, they show the behavior directly, that is, the higher the productivity, the greater the yield (larger beans). Similarly, in the study by Moreira *et al.* (2018), in coffee and macaúba consortium conditions, with about 4.0 m of between the lines of these cultures, resulted in greater productivity and yield of grains compared to full sun. The higher yields are indicative of the high homogeneity of grain maturation, influenced by the fruit filling period (Medina Filho & Bordignon, 2003).

CONCLUSIONS

The height of the coffee crop was the only agronomic performance parameter influenced by tree species.

The system intercropped with tree species did not influence coffee productivity and yield until the 3rd harvest and, for the 5th harvest, intercropping with mahogany favored productivity both at spacings 9 x 13.6 m and 18 x 13.6 m, although the accumulated productivity has not had a treatment effect.

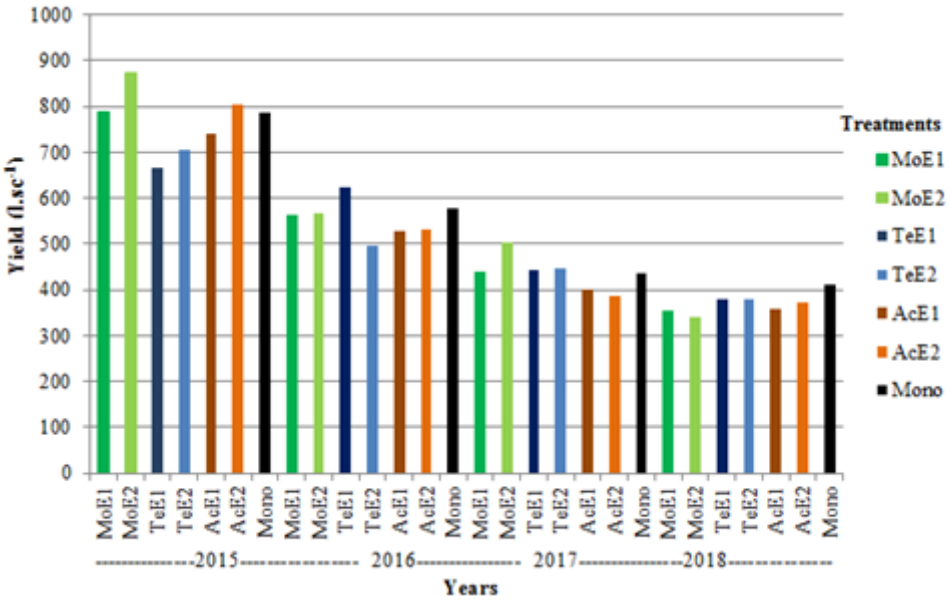

Figure 2: Yield (l/sc) of coffee intercropped with: MoE1 = African mahogany (9 x 13.6m); MoE2 = African mahogany (18 x 13.6m); TeE1 = teak (9 x 13.6m); TeE2 = teak (18 x 13.6m); AcE1 = pink cedar (9 x 13.6m); AcE2 = pink cedar (18 x 13.6m); Mono = coffee crop in monoculture, in 2015, 2016, 2017 and 2018.

CONFLICT OF INTERESTS

There is no conflict of interests in carrying the research and publishing the manuscript.

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