Revista de Ciencias Agrícolas
e-ISSN 2256-2273
https://doi.org/10.22267/rcia.20244101.225

Research article: Other agricultural sciences.

Assessment of transitory crops in cocoa (*Theobroma cacao* L) agroforestry in Páez, Boyacá

Evaluación de cultivos transitorios en agroforestería con cacao (*Theobroma cacao*) en Páez, Boyacá

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Cite: Alfonso-Alfonso, L.; Escobar-Pachajoa, L.D.; Montealegre-Bustos, F.; Carvalho, F. E. L; Carvajal-Rivera, A. S.; Rojas-Molina, J. (2024). Assessment of transitory crops in cocoa (*Theobroma cacao* L) agroforestry in Páez, Boyacá. *Revista de Ciencias Agrícolas*. 41(1): e1225. https://doi.org/10.22267/rcia.20244101.225

Received: February 17 2022. Accepted: January 20 2024.

ABSTRACT

Agroforestry systems incorporate several productive components per unit area to yield efficiency. However, considering the high degree of complexity inherent to interspecific plant-plant interactions, little is known about most of these systems' real productive potential and efficiency. In this context, it is important to analyze the interactions between the components to identify potential favorable associations. The objective of this research was to evaluate the performance of the transitory crops maize (*Zea mays* L) and cowpea (*Vigna unguiculata* L) in a family farming system under three agroforestry arrangements with cocoa in the municipality of Páez, Boyacá, Colombia. A split-plot design was used, where the main plots corresponded to three shade forest species, which were associated with cocoa and the transient crops. The subplots corresponded to three

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planting systems: CS1 cocoa+maize, CS2 coca+beans, and CS3 cocoa+maize+beans. The effect on agronomic and productive variables of transitory crops (maize and beans) was evaluated, and an economic analysis was carried out. For beans, the effect of the cropping system on yield (t. ha-1) stood out, while for maize, the statistical effect was given by the forest x cropping system interaction in most of the variables evaluated. Considering the interspecific interactions found under the influence of different forests, the use of Colombian mahogany as a companion species in these intercropping systems is suggested. The cost analysis revealed that the maize-bean association is more efficient in the equivalent use of land. Therefore, the data obtained reveal more efficient strategies for sustainable cocoa productivity in Colombia.

Key words: Agroforestry; cowpea beans; LER; intercropping; maize; sustainable agriculture.

RESUMEN

Los sistemas agroforestales incorporan varios componentes productivos por unidad de área para rendir con eficiencia. Sin embargo, considerando el alto grado de complejidad inherente a las interacciones interespecíficas planta-planta, se sabe poco sobre el potencial productivo real y la eficiencia de la mayoría de estos sistemas. En este contexto, es importante analizar interacciones entre componentes para identificar potenciales asociaciones favorables. El objetivo fue evaluar el comportamiento de cultivos transitorios maíz-duro (*Zea mays* L) y frijol caupí (*Vigna unguiculata* L) en un sistema de agricultura familiar bajo tres arreglos agroforestales con cacao en el municipio de Paéz, Boyacá. Se empleó el Diseño con Parcelas Divididas, las parcelas principales correspondieron a tres especies forestales de sombrío asociadas a cacao y cultivos transitorios. Las subparcelas correspondieron a tres sistemas de siembra: CS1 cacao+maíz, CS2 cacao+frijol y CS3 cacao+maíz+frijol. Se evalúo el efecto sobre variables agronómicas y productivas de los cultivos transitorios (maíz y frijol) y se realizó un análisis económico. Para frijol destacó el efecto del sistema de cultivo sobre el rendimiento (t. ha^{-1}); mientras que, para maíz, el efecto estadístico estuvo dado por la interacción forestal x sistema de cultivo en la mayoría de las variables evaluadas. Teniendo en cuenta las interacciones interespecíficas encontradas bajo los diferentes forestales, se sugiere el uso de la caoba colombiana como especie acompañante en estos sistemas de cultivo intercalado. El análisis de costos reveló que la asociación maíz-frijol es más eficiente en el uso equivalente de tierra. Por lo tanto, los datos obtenidos revelan estrategias más eficientes para la productividad sostenible de cacao en Colombia.

Palabras clave: Agroforestería; frijol caupí; LER; cultivos intercalados; agricultura sustentable.

INTRODUCTION

In Colombia, the cocoa crop (*Theobroma cacao* L) is of great socio-economic importance since it is produced under family farming. According to MADR (2021), some 52,000 families depend on the cocoa crop, 95% of whom are small farmers. Likewise, in 2022, the national production was 62,158 t in an area of 196,313 ha, with a yield of 0.33t ha^{-1}, with Santander being the main cocoa-producing department with 28,037t in the last year (FEDECACAO- Federacion nacional de cacaoteros, 2023). Particularly in Colombia, this crop has become an alternative for the substitution of illicit crops and economic activity that replaces emerald extraction, an idea that has emerged as an interesting business and productive project, which has generated new territorial scenarios of great importance (Pineda, 2018).

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Therefore, it is necessary to strengthen this sector through cooperative research, technical assistance, and technological transference to ensure the competitiveness of this production chain. Knowledge and technology are the best ways to enable an inclusive, competitive, and sustainable scenario with new economic opportunities for producers in the long term (Cely, 2017).

To achieve an efficient and sustainable cocoa production system, it has been suggested to boost the production model based on family farming, composed especially of small producers, which is accountable for most of the cocoa production in Colombia. To strengthen this production model, in turn, it is necessary to reinforce themes related to productive inclusion, public investment, and the generation of capacities and knowledge. In parallel, the promotion of associativity is also sought, emphasizing land access in sufficient quantity and quality. Machinery provision and inputs and a comprehensive support service beyond technical assistance are similarly crucial (Cely, 2017). Thus, the need for research and disruptive technologies, especially those related to sustainable agriculture, is crucial for ensuring cocoa productivity and associated socio-economic benefits in a long term.

The use of the intercropping approach in agroforestry systems associated with cocoa has been an important technology recently proposed to increase land-use efficiency in cocoa yield (Bai *et al*., 2016). In fact, according to the hypothesis of agroforestry systems, the association of different species has the potential to provide complementarity in the use of resources (Hatfield & Dold, 2019). Moreover, ecosystem services associated with agroforestry may represent an additional advantage, which can generate direct benefits to farmers, including increased land use efficiency, carbon sequestration, and water balance, in parallel to decreased use of fertilizers and the associated costs (Koko *et al*., 2013). Moreover, by incorporating transitory crops into cocoa agroforestry systems, additional economic benefits may be achieved. According to Charani *et al*. (2018), crop intercropping between maize and beans generates higher yields compared to the respective monocultures of these same species. In an analysis to understand how cocoa farmers in Ghana diversify farm income, Amfo & Ali (2020) found that cocoa farmers in new or old plantations can supplement low income from cocoa by growing other crops, which generates a better use of the land and additional income from the sale of other crops.

However, factors such as pressure from urban development, the development of other cash crops, a fall in cocoa prices, and the fact that the crop is not attractive to new generations have negatively impacted cocoa production in Mexico, especially in Tabasco State (Zequeira-Larios *et al.,* 2021). The phenomenon occurring in Mexico also strikes other cocoa-growing regions of Latin America. Accordingly, alternatives have been presented such as the use of intercropping designs, which yield additional goods

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for self-consumption and selling in local markets, increasing the land use efficiency (Somarriba & López-Sampson, 2018; Somarriba *et al.,* 2018).

Despite the potential benefits associated with the adoption of intercropping approaches, it is noteworthy that plant-plant and plant-environment interactions, and the epidemiology of the different cocoa diseases in these systems are subject to several interfering factors, many of which remain little investigated to date (Jaimes-Suarez, 2022; Hatfield & Dold, 2019). Especially, cost-benefit ratios in practical terms, which weigh the advantages of ecosystem services, and income ratios, associated with management expenses and commodity valuation, are still very little comprehended.

In 2020, cocoa production in Boyacá ranked 13th with 1,280t. Specifically, cocoa-producing areas are subdivided into the west and east regions, and the level of technology available for producers is extremely low. Therefore, this research was conceived to propose crop-productive strategies that allow the strengthening of family farming associated with cocoa production. Here, we evaluated the performance of transitional maize and cowpea bean crops in a family farming system under three agroforestry arrangements, associating cocoa and fine woods in the municipality of Páez, Boyacá.

MATERIAL AND METHODS

Location. The research was carried out in an experimental plot located in the village of Pan de Azúcar in the municipality of Páez, Boyacá, at 5°5’50.50”N, 73°04’16.72”W, and 890 masl. The annual temperature ranges between 18 and 24°C (night/day), the annual precipitation is between 2,000 and 4,000mm, and daily average humidity equals 85%.

Cropping systems and shade trees*.* The experiment was carried out in an agroforestry system with special cocoa and fine wood, with three years of planting. Cropping systems under the influence of three shade trees were evaluated. The cropping systems consisted of three mixes: thus CS1=maize in sole-crop design, CS2= cowpea beans in sole-crop design, and CS3= maize-cowpea beans mixed-crop association. The three shade trees were *Cariniana pyriformis*, *Tabebuia rosea*, and *Terminalia superba*.

Experimental Design. The experimental design consisted of a split-plot design with two independent randomization steps. The field was divided into two blocks (replicates). Each block was divided into three main plots of 28 x 24 m each. The three shade trees were randomly assigned to the main plots for each block separately. Shade tree species were planted in double rows at 4 m between trees and 12 m between double rows in each plot. Cocoa (3 x 3 m) was planted in the middle of the double rows. Every main plot was split into three sub-plots to accommodate the three different cropping systems. Separately, for each main plot, the cropping systems were randomly allocated to the

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three sub-plots of 9.3 x 24 m each. The main- and sub-plot factors were randomized according to a randomized complete block design, taking main plots as blocks for the last one and replicates as blocks for the former (Krzywinski & Altman, 2015). In each subplot, ten plants located in the center of the rows corresponding to transitory crops were selected for the measurement of variables.

Crop management. The sowing of the maize ICA V-305 and cowpea beans variety ICA N°1125 was carried out in October 2019 under a planting distance of 25cm within plants and 80cm between rows. Fertilization for the treatments was applied 20 days after sowing (das) with foliar fertilizer (15cc/pump), and the second was at 40 das (25cc/pump). The crop was also continuously monitored for chemical and/or mechanical control of weeds, pests, and diseases. For pest control, the biological product “safermix” (30g/pump) was applied at intervals of 8 days between applications.

Traits evaluated. When the plants reached harvest maturity, agronomic and productive traits were recorded. For cowpea beans, plant height (cm), stem diameter (2cm above the ground (mm)), number of pods per plant (NV), number of grains per pod (NG), and weight of 50 seeds (PCS) (g) were evaluated. For maize, plant height (flag leaf and ear - cm), stalk diameter (mm), Ear length (cm), Ear diameter (mm), Ear weight with husk (g), ear weight without husk (g), number of rows (NF), number of grains per row (NGF), and the weight of 50 seeds (g) were recorded. For the transient crops, the number of plants in the useful area of the plot was counted, and the yield data were extrapolated to kg ha^{-1}.

Additionally, the productivity of maize and cowpea mixture were compared by the total LER (Nassary *et al.,* 2020). The calculation of the Land Equivalent Ratio (LER) was carried out to compare the treatments (T1=maize in sole-crop design, T2= cowpea beans in a sole-crop design, and T3= maize-cowpea beans mixed-crop association). LER was calculated and analyzed using the methodology described by Deb & Dutta (2022) Equation 1:

$$LER = \sum_{i-1}^{2} \left(\frac{Y_{iMC}}{Y_{iSC}} \right) \quad \text{Equation 1.}$$

Where indicates the total yield obtained for maize or cowpea beans, respectively, when they were grown in a mixed-crop design and denotes the yield of these same crops when grown in a sole-crop design.

The LER (Land Equivalent Rate) analysis has three possible outcomes for associated crops: yield advantage (LER > 1), yield disadvantage (LER < 1), and intermediate outcome (LER =1) (Vandermeer, 1989).

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Statistical analysis. A linear mixed model with growth and yield variables as the response variable was used to analyze the following fixed effects: shade tree (S, whole-plot factor), cropping system (CS, sub-plot factor), and their interaction effect S: CS. The split-plot design had two randomization units represented in the linear model (whole-plots and sub-plots) by a random effect, so each randomization unit has its error term. The model compares shade trees at the whole-plot level, so the whole-plot error is the relevant error term. The cropping systems were compared at the sub-plot level, so the sub-plot error is the relevant error term (Equation 2). Furthermore, the model contained a block (replicates) effect because the whole plots were randomized in complete blocks. Separate analyses were conducted for maize and beans. The ANOVA table reported used the Kenward-Roger approximation for the degrees of freedom (Kenward *et al*., 1997). All analyses were performed in the software R using the lmerTest package (Kuznetsova *et al*., 2017; Meier, 2022).

$$Yijk = \mu + \alpha i + \beta j + (\alpha\beta)ij + \eta k(i) + \epsilon ijk \quad \text{Equation 2.}$$

Where αi: forestry fixed effect, βj: cropping system fixed effect, $(\alpha\beta)ij$: forest*cropping system interaction term, $\eta k(i)$: main plot error, ϵijk: split plot error.

Financial Evaluation. The income and costs of transitory crops in cocoa-timber systems were estimated in the treatments: T1=maize in sole-crop design, T2= cowpea beans in a sole-crop design, and T3= maize-cowpea beans mixed-crop association. These treatments were evaluated based on cash flows using financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (B/C) (Meza, 2013; López-Sánchez & Musálem, 2007). The discount rate used for the financial analysis is 9%, which corresponds to the social discount rate established by the National Planning Department (Piraquive *et al.,* 2018).

RESULTS AND DISCUSION

The analysis of variance indicated that in the cowpea crop, the planting system significantly influenced the stem diameter (SD), production per plant (PROD_P), and total production (PROD_T) ($p \leq 0.05$). While observing the interaction of forestry x cropping system, a significant effect was present only in stem diameter (Table 1).

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Table 1. Mean squares of the ANOVA for agronomic traits in cowpea beans (*Vigna unguiculata*) grown under agroforestry systems with cocoa.

Source of variation	DF	PH	SD	NP	NSP	PROD_P	PROD_T
Block (Bl)	1	45.34 ns	10.23 ns	3.24 ns	22.81 ns	283.71 ns	0.16 ns
Forest (F)	2	103.84 ns	6.67 ns	18.88 ns	5.05 ns	196.11 ns	0.11 ns
Cropping system (CS)	1	4.03 ns	9.92*	9.08 ns	0.22 ns	534.13*	5.89***
F x CS	2	110.03 ns	28.77***	36.92 ns	0.20 ns	203.50 ns	0.15 ns

PH: Plant height (cm), ST: Stem diameter (mm), NP: Number of pods per plant, NSP: Number of seeds per pod, PROD_P: Production per plant (kg), PROD: Production total (t/ha). * = significant differences, ns= non-significant differences.

Regarding maize cultivation, the planting system significantly influenced the ear weight with husk (EW) and total production (PROD_T). The forest x cropping system interaction had a significant effect on most of the variables evaluated, except for ear diameter (ED) (Table 2).

Table 2. Mean squares of the ANOVA for agronomic variables in maize grown under agroforestry systems with cocoa.

Source of variation	DF	SH	FLH	SD	EL	ED	EWH	EW	PROD_P	PROD_T
Block (Bl)	1	36.26 ns	17.3 ns	19.34 ns	0.34 ns	7.68 ns	506.8 ns	457.32 ns	3.54 ns	0.72 ns
Forest (F)	2	665.68 ns	577.9 ns	3.03 ns	9.24 ns	7.27 ns	273.7 ns	117.52 ns	4.87 ns	1.47 ns
Cropping system (CS)	1	96.47 ns	68.0 ns	0.02 ns	10.50 ns	84.16 ns	2239.4*	277.16 ns	3.95 ns	65.14***
F x CS	2	2654.96**	3177.6***	16.08**	26.14**	81.18 ns	6045.9***	3082.82**	2.61**	17.39***

SH: Spike height (cm), FLH: Flag leaf height (cm), SD: Stem diameter (mm), EL: Ear length (cm), ED: Ear diameter (mm), EWH: Ear weight with husk (g), EW: Ear weight without husk (g), PROD_P: Production per plant (kg), PROD_T: Production total (t/ha). * = significant differences, ns= non-significant differences.

The comparison of the mean for agronomic behavior of cowpea beans. Based on the results of the ANOVA, the comparison of the means test was carried out for the agronomic performance of the cowpea beans. The stem diameter was greater in CS2 under the savannah oak forest. On the other hand, production per hectare was significantly higher in CS2 for the three trees (Table 3).

Table 3. Performance of agronomic variables of cowpea beans (*Vigna unguiculata*) under the effect of three forest associations and two cropping systems in the locality of Paez, Boyacá.

Variable	Forest association					
	Colombian mahogany[1]		Savannah oak[2]		Limba[3]	
	CS2	CS3	CS2	CS3	CS2	CS3
Plant height (cm)	55.4a	59.4a	62.0a	61.6a	63.5a	61.0a
Stem diameter (mm)	6.67b	6.75b	9.05a	6.55b	6.30b	7.0b
Number of pods per plant	12.9a	12.9a	16.2a	13.5a	11.4a	12.4a
Number of seeds per pod	9.27a	9.04a	8.56a	8.48a	8.54a	8.59a
Production per plant (g)	32.4ab	31.0ab	39.0a	29.6b	26.7ab	24.6ab
Production (t/ha)	0.78a	0.37bc	0.93a	0.35bc	0.64ab	0.30c

a, b, and c different letters mean statistically significant differences between treatments (p<0.05; Tukey test). [1]Cariniana pyriformis L, [2]*Tabebuia rosea* (Bertol) CD. [3] *Terminalia superba* Engl. & Diels

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The incorporation of maize cultivation in CS3 affected the final cowpea production, evidencing a competitive effect of maize in the intercropping (Hamd-Alla *et al*., 2014). In cropping systems that combine cereals and legumes, productivity is largely determined by the relationship between factors such as crop varieties, soil fertility and humidity, which comprehensively influence the mutual benefits and/or competition between the crops that make up the intercropping system (Rusinamhodzi *et al*., 2012; Namatsheve *et al*., 2021). The reduction in cowpea yields in association has been classically attributed to the effects of competition for light on the components of the photosynthetic structure, as well as competition for land resources (Vélez *et al*., 2007; Vélez *et al*., 2011). Masvaya *et al*, (2017), when evaluating cropping systems, found that intercropping compromised cowpea yields compared to cowpea-only stands, which was related to the lack of differentiation of underground niches in the distribution of roots between maize and cowpea.

The comparison of the mean for maize agronomic behavior. In general, eight out of the nine variables assessed in maize exhibited the highest values when grown in association with Colombian mahogany in the CS1 cropping system. Conversely, Savanna oak presented the lowest values in most of the variables, with no statistically significant differences between the two cropping systems, except for total production, where CS2 significantly exceeded CS3 (Table 4).

Table 4. Performance of agronomic variables of maize (*Zea mays*) under the effect of three forest associations and two cropping systems in the locality of Paez, Boyacá.

Variable	Forest association					
	Colombian mahogany[1]		Savannah oak[2]		Limba[3]	
	CS1	CS3	CS1	CS3	CS1	CS3
Spike height (cm)	170ac	154bd	140 abcd	146abcd	145cd	161ab
Flag leaf height (cm)	168ac	149bd	135abcd	141abcd	143cd	160ab
Stem diameter (mm)	11.7ab	11.0ab	11.3ab	10.4b	10.6b	12.0a
Ear length (cm)	12.75a	10.29b	10.29ab	10.19ab	9.54b	10.26ab
Ear diameter (mm)	39.2a	34.9b	34.6ab	32.4ab	34.4ab	35.8ab
Ear weight with husk (g)	87.7ab	53.1cd	55.8abcd	48.3abcd	57.2bd	72.5ac
Ear weight without husk (g)	60.2ac	39.5bd	38.5abcd	34.8abcd	36.0cd	51.0ab
Production per plant (g)	188.4ac	128.0bd	71.0abcd	52.9abcd	78.0ab	120.8cd
Production(t/ha)	4.52ac	1.49bd	1.75ab	0.62cd	1.87abc	1.45abcd

a, b, c and d different letters mean statistically significant differences between treatments ($p<0.05$; Tukey test).

[1]Cariniana pyriformis L, [2]*Tabebuia rosea* (Bertol) CD. [3] *Terminalia superba* Engl. & Diels

The results demonstrated a differential impact of the forest type on maize productivity per plant. Specifically, under the canopy of Colombian mahogany, the CS1 system exhibited significantly higher production compared to CS3. In contrast, under the Limba Forest, the CS3 system stood out with higher production per plant. Finally, for savanna oak, production per plant did not show statistically significant differences between

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cropping systems. However, concerning total production, a differential impact of the cropping system was observed, with CS1 consistently proving the most productive across all types of forests. Therefore, it can be inferred that the significant difference in total production per hectare was determined by planting density rather than productivity per plant, especially under savanna oak and Limba forest.

The evaluation of intercropping systems has shown that in intercropping, there may be cases of reduced yield associated with competitive interactions or cases of productive advantages through interspecific cooperation processes (Zhang & Li, 2003; Kermah *et al*., 2019; Ziaie-Juybari *et al*., 2021). In the present investigation for production per plant in maize, both a competition effect and a possible compatibility effect were observed, depending on the forestry associated with the cropping system.

The cultivation of maize requires temperatures ranging between 25 and 30°C and is quite demanding in terms of sunlight (Sánchez *et al.*, 2014). Therefore, for its integration into agroforestry systems, it is essential to know the effects of the architecture and dynamics of the tree canopy of different species since they affect the availability of radiation and, finally, the photosynthetic rates of associated crops (Farfán, 2014). The Colombian mahogany forest is characterized by a straight trunk with a narrow crown; it also exhibits small and thin leaves, which contribute to greater light filtration. Agudelo *et al.* (2018), when evaluating the physiological performance of cocoa under the shade of three forest species in Santander, found that cocoa established under the shadow of *C. pyriformis* presented higher rates of photosynthesis in the wet and dry seasons, which was associated with greater light filtration under this forest.

It is well established that planting systems can significantly influence maize components and yield (Charani *et al*., 2018; Sanfo *et al*., 2022; Zhanbota *et al*., 2022). In this study, under the Colombian mahogany forest, both per-plant and total yields were higher in the CS1 system compared to CS3. Conversely, under Limba in the CS3 intercropping system, higher per-plant yield values were observed compared to CS1. Similarly, Ebel *et al*. (2017) reported that in polyculture (an association of maize and beans), each maize plant produced 68.3 g, which was 1.2 times higher than the yield per plant in monoculture. For their part, Masvaya *et al*. (2017) reported that in maize-cowpea intercropping, while there was a decrease in cowpea production, maize yield was not adversely affected and even showed improvement in some cases. This performance has been attributed to several advantages associated with intercropping systems, including nitrogen fixation by legumes, which benefits cereal crops (Legwaila *et al*., 2012). Furthermore, it has been documented that in some cases, maize plants associated with beans cease competing for vertical space, resulting in a larger stem diameter (Li *et al*., 2023), a phenomenon observed in our study with maize under Terminalia in the CS3 system.

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Maize and beans exhibit significant differences in photosynthetic plasticity, light requirements, and nutritional demands, particularly in nitrogen. Maize, a C4 species, generally demonstrates a light saturation level exceeding 1,500μmol m-2 s-1, although it may vary based on nutritional conditions (Usuda *et al*., 1985). In contrast, cowpea, a C3 metabolism species, displays a light saturation level below 1000μmol m-2 s-1 (Surabhi *et al*., 2009). Within this context, it is crucial to recognize that the performance in intercropping systems considers various factors, including planting density, resource competition (water, nutrients, sunlight), and the selection of compatible maize and bean varieties concerning growth and development. Furthermore, for the establishment of crops associated with Agroforestry Systems (AFS), it is imperative to factor in the main crop's age, crop type, planting system, agronomic management, as well as spatial and temporal arrangements to optimize productivity and resource efficiency (Arcila *et al*., 2007; Palomino de la Cruz, 2019).

Considering the above, in the case of the maize-cowpea association, the mixing ratio of 50% maize to 50% beans planted in alternate rows (Takim, 2012), as employed in the current study, has been suggested as a suitable intercropping pattern. On the other hand, considering that high productivity per hectare was observed under the Colombian mahogany-maize arrangement, these specific AFS-associated crop models are recommended.

Land equivalent ratio (LER). The LER for the maize-cowpea beans intercropping system showed an increase in soil use efficiency of 31% concerning the cowpea beans system, indicating that intercropping improves productivity and efficiency per unit area (Table 5). Using intercropping requires less land to produce the same yields than the monoculture strategies, thus presenting a better use of the land (Rediet *et al*., 2017). Furthermore, the use of intercropping may directly increase the efficiency of resources using water, light, and nutrients, for example, compared to monocultures, which generate a proportional benefit in terms of expenses associated with the production system (Nassary *et al.,* 2020; Bitew *et al.,* 2021).

Table 5. The land equivalent rate for different planting systems of maize (*Zea mays*) and cowpea beans (*Vigna unguiculata*) under the effect of three forest associations with cocoa cultivation in the locality of Paez, Boyaca.

Planting system	Yield (t/ha)	
	Maize	Beans
Maize	2.71±0.5	-
Cowpea beans	-	0.78±0.04
Maize-cowpea beans	1.19±0.5	1413.8±0.04
LER	1.46	1.31

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Similar results were obtained by Charani *et al.* (2018), where LER was above 1.0 (1.24) in two rows of beans between two rows of maize, with an increase in yield equal to 24% while reducing the occurrence of weeds. In addition, shade trees in this physiological stage do not exert great competitive pressure for resources due to their youthfulness. Moreover, the intercropping is favored by the environmental conditions of the trial and the fact that there were no water or nutrient stresses, which reduces the competition pressures and promotes the better features of the association (Rediet *et al.,* 2017).

Financial evaluation. Costs were calculated based on the establishment and maintenance of each transient crop. Income was estimated from the productivity obtained for each treatment and AGRONET prices. Finally, for the analysis, it was considered that the crops have a cycle of 4 months; therefore, the producers can obtain two harvests in the year. Table 6 shows the costs and revenues for one crop in each treatment.

Table 6. Crop Budget for different planting systems of maize (*Zea mays*) and cowpea (*Vigna unguiculata*) under the effect of three forest associations with cocoa cultivation in Paez, Boyacá.

Period	**Month 1**	**Month 2**	**Month 3**	**Month 4**
Transitory species	**Maize**			
Incomes*				$ 6.479.995
Costs	$ 2.720.738	$ 1.174.462	$ 187.579	$ 280.772
Net flow	-$ 2.720.738	-$ 1.174.462	-$ 187.579	$ 6.199.223
Transitory species	Beans			
Incomes				$ 4.552.397
Costs	$ 2.812.736	$ 925.949	$ 131.425	$ 232.981
Net flow	-$ 2.812.736	-$ 925.949	-$ 131.425	$ 4.319.416
Transitory species	Maize-beans			
Incomes				$ 4.784.181
Costs	$ 2.629.338	$ 1.025.116	$ 187.579	$ 256.876
Net Flow	-$ 2.629.338	-$ 1.025.116	-$ 187.579	$ 4.527.305

*Values are given in Colombian Pesos COP$

According to the table above, it is evident that the establishment costs of maize cultivation are lower than those of bean cultivation; however, the maintenance costs of maize cultivation are higher than those of bean cultivation. On the other hand, beans have higher prices than maize, but yields are lower, thus generating a lower income than maize. Table 6 estimates the financial indicators for each treatment.

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Table 7. Financial indicators for different planting systems of maize (*Zea mays*) and cowpea (*Vigna unguiculata*) under the effect of three forest associations with cocoa cultivation in the town of Paez, Boyaca.

Indicators*	Maize	Beans	Maize-beans
NPV	$ 1,990,553	$ 362,401	$ 595,330
IRR	17%	4%	6%
Benefit/Cost Ratio	1.49	1.11	1.17

*Values are given in Colombian Pesos COP$

All three treatments have good financial indicators since they have a positive NPV, an IRR higher than Social Discount Rate, and a Benefit/Cost ratio greater than 1.

Analyzing the cultivation of maize and beans as a transitory crop within a cocoa-timber agroforestry system, the most profitable transitory crop is maize, since it generates higher economic indicators than beans. For each peso invested in the maize crop, the farmer obtains $1.49, while in the bean crop, he obtains only $1.11. In relation to the net present value generated by the maize crop, it generates more than one million pesos more than the bean crop.

Finally, the maize crop in the cocoa agroforestry system is the transitional crop in association that generates the best income, as shown in Table 7, where the financial indicators of this treatment are higher, due to the high productive yields of maize. That is why, the $NPV_{Maize} > NPV_{Maize\text{-}cowpea\ bean} > NPV_{cowpea\ beans,}$ $IRR_{Maize} > IRR_{Maize\text{-}cowpea\ beans} > IRR_{cowpea\ beans}$, and $(B/C)_{Maiz} > (B/C)_{Maize\text{-}Cowpea\ beans} > (B/C)_{cowpea\ beans,}$ being financially recommendable to introduce maize crops in the cocoa agroforestry system.

These results are also like those found by Cerda *et al.* (2014), in which they analyzed the contribution of cocoa agroforestry systems to the income of producer families in five Central American countries. Their results highlight the income generated by the transitory fruit and timber crops that are part of the agroforestry system. These authors support the idea that intercropping systems can generate a considerable income stream for the household by generating products with high household consumption value and low cash costs, which contribute to household savings and food security. According to Somarriba *et al*. (2018), by using agroforestry practices, crop yields are more consistent over the years, and by diversifying production, economic risks are reduced.

CONCLUSIONS

The evaluation of the growth and yield of transitional crops under agroforestry systems showed that the cropping system mainly influenced the total production variable, both for beans and maize. The forest-crop system interaction presented a significant effect on most variables only for maize. However, considering the interspecific interactions found under the influence of the different forests, the use of Colombian mahogany as

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a companion species in these intercropping systems is suggested since it favors higher growth and productivity, representing an opportunity for crop diversification and food security for farmers.

The maize or bean in a sole-crop design performs better than the maize-beans mixed-crop association in terms of yield per hectare; however, the cost analysis revealed that the maize-beans association is more efficient in equivalent land use. The financial evaluation also corroborates these results since the following factors are present: high bean prices, low bean maintenance costs, and high maize yields, which generate better financial indicators for the farmer.

ACKNOWLEDGMENTS

We thank the Corporación Colombiana de Investigacion Agropecuaria (AGROSAVIA) for providing the infrastructure and support for the development of this research. The project was financed by the Sistema General de Regalias through the project "*Investigación, desarrollo e innovación en cacaos especiales bajo sistemas agroforestales*". (BPIN 20013000100255). In addition to all the support and collaboration in the development of the agronomy thesis of the main author, Mr. Hildo Morales, in the municipality of Paez, Boyacá.

Conflict of interest: The authors declare that there is no conflict of interest.

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