Sustainable Agroforestry in Madre de Dios: Assessing the Impact of Existing Saplings on Growth of *Theobroma cacao* and *T. grandiflorum*

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Abstract

Deforestation in the region of Madre de Dios outweighs the active reforestation efforts. A large part of this is due to unsustainable farming and lack of technical education. The Native food forest is an example of self-sustaining agroforestry developed by the Alliance for a Sustainable Amazon (ASA) at Finca Las Piedras, Madre de Dios. This study highlights the impacts of shade created by existing saplings on cacao and copoazu trees planted in 2017. The growth index was calculated considering the height and circumference of the trunk and was analyzed in comparison to light availability for each tree. A greater proportion of the variation in cacao trees growth is explained by the amount of light and such relationship was statistically significant. Slightly similar pattern is found in copoazu trees, but more sampling would be required. The results suggest that existing saplings might negatively impact cacao and copoazu growth by preventing light. Our findings are discussed in hopes of recommending farming practices that are more cost and labor efficient. Adopting self-sustainable farming techniques can mitigate deforestation and instead promote reforestation when conducted with right planning.

Introduction

Madre de Dios region, located in the Southeastern Peruvian Amazon has become a hotspot for deforestation in the recent decade. By 2017, approximately 27,465 acres were lost due to deforestation (MAAP, 2018; Fig.1), and even though farming is one of the most important land uses, about 80% of all deforestation is on land that is not viable for agricultural purposes (Ministerio del Ambiente, Peru). To prevent ecological disasters and irreversible loss of biodiversity, sustainable agriculture and reforestation efforts remain as key components of land management. Currently, secondary regrowth covers about 4.5 million km2 or 1.2% of the humid tropical forests in the world, and although the rate it is growing back (0.08% per decade) (Asner et al., 2009), it is still not enough to compensate reforestation rates,

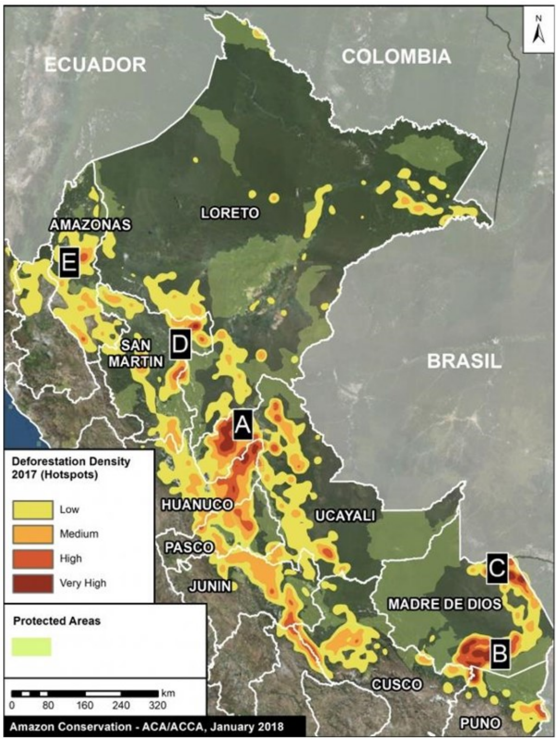

Figure 1. Deforestation Hotspots in Peru (MAAP,2018).

particularly in Madre de Dios.

Farmers in the region grow papayas, corn, cacao, watermelon, pineapple, cassava, banana, rice, and other various crops to adapt to the changing market and in hopes to gain economic profit (Vilca, 2017). Their methods, however, are highly unsustainable due to their lack of education and technical training (Theisen, 2019). In 2017, shortly after the Alliance for a Sustainable Amazon (ASA) bought the property of Finca Las Piedras, a sector was burned due to a spreading forest fire started by a neighbor. Farmers tend to regularly clear the rainforest to maintain agricultural production (Theisen, 2019). The slash and burn method commonly used brings nutrients to the top of the soil but also deteriorates it overtime proving to be very ineffective (Vilca, 2017).

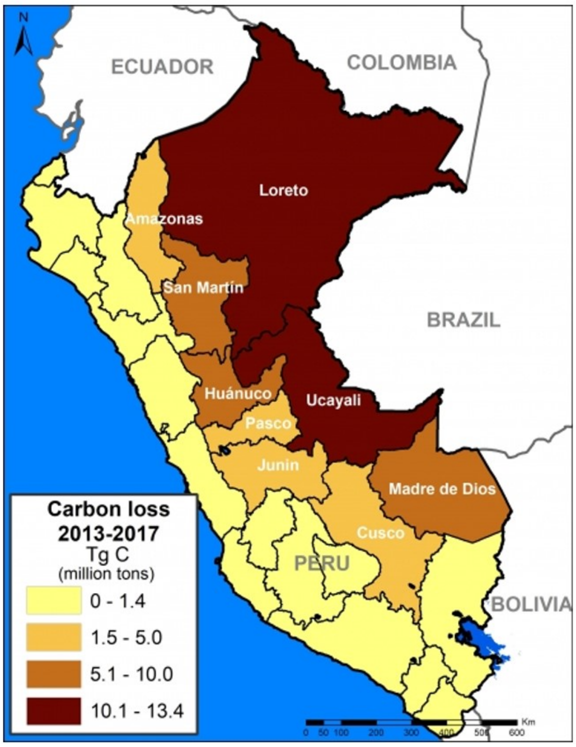

Figure 2. Carbon loss in Peru 2013-2017 (Finer, 2017).

In addition to the economic impacts, the environmental impacts pertain to the amount of carbon sequestered by the trees. In this region, the amount of carbon sequestered is decreasing because of land clearing practices for agricultural purposes. In 4 years, 7 million metric tons of carbon have been lost (Finer, 2017, Fig 2). By practicing crop rotation and crop diversity, the soil of the land and carbon can be preserved.

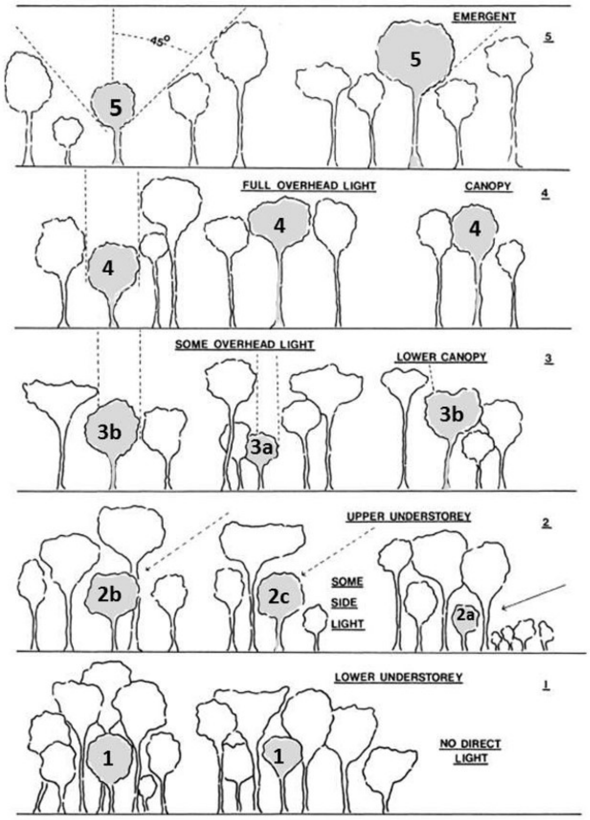

Figure 3: Scale of light (Phillips, 2018).

As part of the Alliance for a Sustainable Amazon's objectives, they promote reforestation and implementation of agroforestry plots as a sustainable method for producing food while keeping the forest connected. Increasing cacao production is a way to promote social and economic growth, while pursuing a sustainable development in this region (Vilca, 2017). After the fire, ASA cleared rows within the sector to plant a native food forest. They planted around 600 trees varying of the Malyaceae family, especially cacao (*Theobroma cacao*) and copoazu (*Theobroma grandiflorum*). The native food forest is meant to provide self-sustaining food sources for people and wildlife rather than providing economic profit at Finca Las Piedras. This initiative is setting the example of reforestation and viable agroforestry for the closest neighbors and all the region. In 2017, the area of secondary forest where the fire had taken was divided into zones with abundant invasive African Cattle grass (*Brachiaria sp*.) and zones with various saplings of pioneer species that had been trying to thrive as part of the forests' secondary regrowth. Instead of clearing the entire plot, ASA chose to clear rows where they planned to plant the trees. It was a way to keep the secondary forest intact and contribute to it, hopefully accelerating the reforestation process. However, saplings with greater growth rate than cacao o copoazu could have prevented light to them.

In this study I explore the relationship of light availability with growth of cacao and copoazu trees, as it might inform how to improve agroforestry techniques and assess the importance and impact of the presence of native shade trees left to grow in between planted rows. The native food forest provides a tie between reforestation and sustainability and if implemented by other farmers, it can be a potential mitigating factor toward the loss of carbon and biodiversity in the region.

Methods

I surveyed 242 of the approximately 600 trees that were planted in 2017 during ASA's reforestation project. Cacao and copoazu trees were chosen for the analyses, with a total of 119 and 42 individuals, respectively. A diagram of their location was produced for further studies (see appendix A). Data on measurements and qualitative indexes were taken for each cacao and copoazu plant. Circumference was measured at 0.50 m height. Total height was calculated from the center of gravity to the ground. Thus, growth index was calculated as the following:

$$\mathbf{c * h = GI}$$

Where:
c: circumference
h: height
GI:growth index

Light availability was measured as the amount of light that trees receive by using the 1-5 scale (fig. 3), where 5 is considered direct sunlight.

Additional data was taken such as, the denseness of leaves on a scale from 1 to 5, where 5 represents the bushiest. Finally,

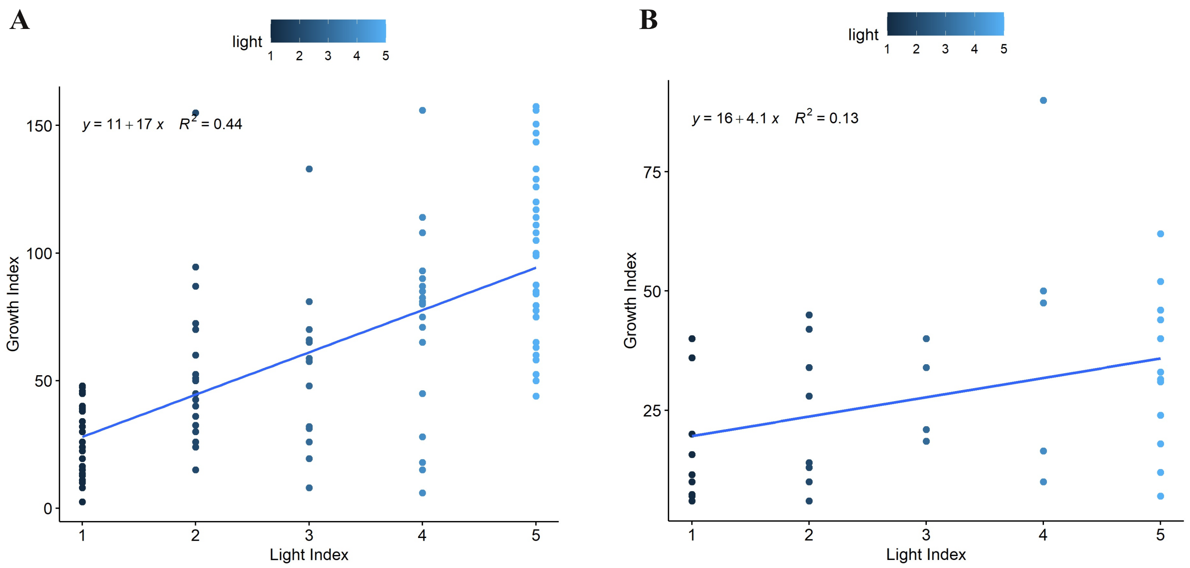

Figure 4: Growth of cacao (A) and copoazu (B) with respect to light availability.

number of fruits was considered excluding the rotten and green ones. The location was noted in the raw data sheet as well as the weather conditions to attain accurate, uniformed results. All data was then analyzed in an excel spreadsheet. I calculated the growth index of each tree by multiplying the height by the circumference. A pie graph was also made to represent the various categories marked within the plot. The amount of shade was compared to the growth index for cacao and copoazu in the program R to determine if there was any relationship between the two factors. I created a scatterplot with a line of regression to determine if this relationship was statistically significant for both species.

Results

There was a total of 119 cacao, 42 copoazu, 35 light gaps, and 45 unidentified species in the plot I sampled (Fig 5, See Appendix A for complete map). After inputting the data into R, A Shapiro-Wilk normality test was run for both cacao and copoazu to determine the P-value and the value of W. The p-value for cacao was .0004552 and the value of W was equal to .95397. For copoazu the p-value was .004192 and the value of W was equal to .91505.

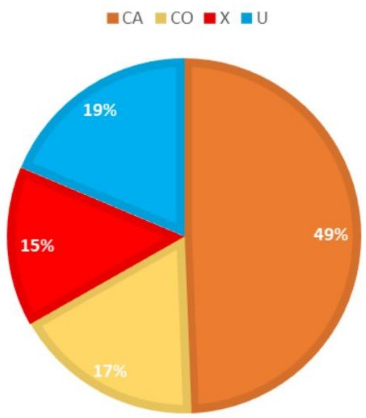

Figure 5: Proportion of surveyed trees.

The R-squared values of each species also showed the variation explained by light, but these results were only statistically significant for cacao (Fig.4). Cacao showed 43.51% variation, while Copoazu showed a variation of 10.89%. The final P-value of copoazu equals .01868 and the p-value of cacao is 2.2e-16.

Discussion

Out of the 240 total trees surveyed, a majority of those were *Theobroma cacao*. The data for *Theobroma grandiflorum*, or copoazu trees, was statistically insignificant based on the p-value of .01868, which is larger than .05. A small sample size may explain this statistical insignificance, as copoazu trees only accounted for 42 of the 240 trees surveyed. Although a clear positive trend can be seen in figure 5, only 13% of the data mimics this trendline. As for cacao, the data seems to resemble a clear statistical significance between light index and growth. The R-squared value of .44 shows that 44% of the data mimics the positive, upward sloping trendline.

According to the data, the height and diameter of the trees increased as the light it received increased. The more light received by a cacao tree, the taller and healthier the tree grew. This is shown with an extremely small p-value of 2.2e-16, which is much smaller than the conventional threshold of .05; therefore, we can accept the hypothesis that there is a strong correlation between the growth of a cacao tree and the amount of light it receives. The amount of fruit and the density of the trees' leaves were also tested for significance but proved to be statistically insignificant (Fig. 6, see appendix).

The amount of shade a tree received was primarily due to the surrounding pioneer species of existing saplings that were left in the plot in 2017. The partial clearing of rows that took place has proven to be slightly ineffective according to my data. The pioneer species had outgrown the trees planted in 2017 and shaded them, ultimately absorbing their light and stunting their growth. I would suggest selectively planting trees in preexisting light gaps rather than clearing rows near the preexisting saplings because those trees would thrive more with copious amounts of light. This strategy both promotes the regrowth of the secondary forest and is more time and labor efficient than clearing rows for new trees. The efforts of ASA to regenerate the forest were still achieved, but the data shows a threshold where trees no longer received sufficient light and lacked nourishment.

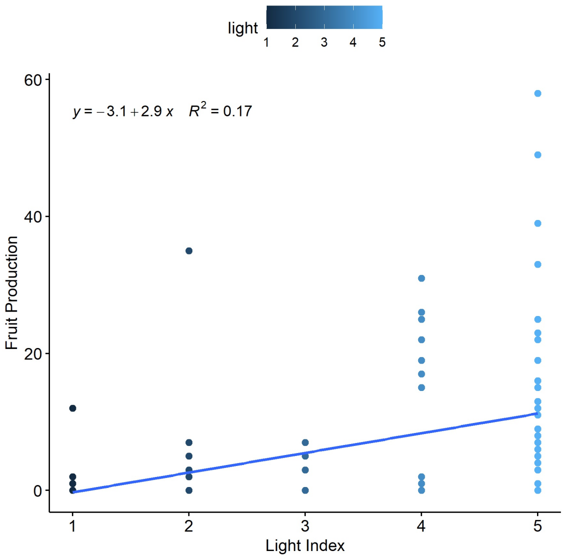

Figure 6: Cacao fruit production along a light gradient.

The plot continues to be maintained, but with only 2 grounds keepers, only about half of it is cleared of weeds and invasive grass. Based on this study, the parts of the plot that aren't maintained seem to be thriving more. This is an indicator that there is not potentially a need to maintain the trees forever once they are planted. The land and soil could be richer from the other various species surrounding it, leading it to be more organic. This would help fruit producing trees thrive and could potentially lead to larger yields for farmers. The need for the tree to be maintained could potentially only apply to the immature sapling. Epiphytes and lianas can kill a tree during its young stages, but as the tree grows to be mature, they have less of an effect on their growth. The plants and various saplings growing around the tree cannot sprout past the mature tree but rather around it. I believe another study could be done to better understand the role of epiphytes on mature trees, although, my study leads me to suggest that the only parts of the plot that need to be maintained are the areas the saplings are growing and/or planted. Planting an immature sapling in an open gap of light and nurturing it until it is mature could conserve resources and promote secondary regrowth in a more sustainable way. For example, this would allow farmers to focus on certain parts of a plot rather than clearing the land, entirely or even only rows, and instead plant trees in a rich patch of soil with surrounding forest. In turn giving them higher yields of product, less labor, and a more focused perspective.

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Supplementary Material

Appendix I: Inventory map of the native food forest.

KEY:	
CA- Theobroma Cacao	
CO- Theobroma Grandiflorum (copasu)	
X- Empty spot	
U- Unkown (Inga Edulus and various other trees)	

CA	U	CA	CO	U	U	U	U	X	CA	U	CA
CA	U	CA	CA	U	U	U	CA	CA	CA	U	CA
CA	U	CA	CO	X	CA	CA	X	CA	CA	U	CA
CO	CA	CO	CA	CO	CA	CO	CA	CO	CA	CO	CA
U	CA	U	CA	CA	CA	U	CA	U	CO	U	CA
CO	U	CA	CO	X	CA	CA	U	CA	CA	X	CA
CO	CA	CO	CA	CO	CA	X	CA	CO	CA	CO	CA
U	CA	U	CA	X	CA	U	CA	U	CA	U	CO
X	X	CA	U	U	X	CA	X	CA	CA	X	CO
CO	CA	CO	CA	CO	CA	CO	CA	CO	X	CO	CO
U	CA	U	CA	U	CA	U	CA	CA	CA	X	CA
U	U	CA	CA	U	CA	CA	X	CA	CA	X	CA
CO	CA	CO	CA	CO	CA	CO	CA	CO	CA	CO	CA
U	CA	U	X	X	CA	U	CA	X	CA	U	CA
CA	X	CO	CA	X	CA	CA	X	CA	CA	U	X
CA	CA	CO	CA	CO	X	CO	CA	CO	CA	CO	CA
X	CA	X	CA	U	CA	X	CA	U	CA	U	CA
CA	X	CA	X	U	CA	CA	CO	X	X	X	CA
CO	CA	CO	CA	CO	CA	CO	CA	CO	CA	X	CA
U	CA	U	CA	U	CA	U	CA	U	CA	U	CA

Supplementary Material

Appendix II: Cacao density of leaves in a light gradient.