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Shade's Benefit: Coffee Production under Shade and Full Sun

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Abstract

Coffee has major importance in tropical landscapes from agronomic, economic and ecological perspectives. Yet the conversion of shade-coffee into full sun monocultures has deep effect on the potential of those systems to conserve biodiversity and ecosystems services (such as pest control and pollination). Despite of this, effect of shade on production has not been sufficiently addressed, particularly in Brazil, the world major coffee producer. This study compared the performance of shaded coffee and full sun management in terms of productivity and production costs. The survey was conducted in Municipality of Mirante da Serra, in the Brazilian Amazon and eight coffee agroecosystems, four under shade and four under full sun were investigated. The results indicate that shaded systems have lower production costs requiring less working hours than sun plantations. The average production cost of shaded agroecosystems was 49.63%, while in systems under full sun, this value was 82.2%. Shaded and full sun productivity did not differ significantly, with higher variance in the former, showing that shaded systems are more heterogeneous. Shaded coffee agroecosystems presented an economically and environmentally viable alternative. The lower production cost enhances economic viability of these ecosystems in Amazon as well as in the rest of the tropics. Such efficiency may have influenced the persistence of these managements, despite the worldwide agriculture intensification tendency.

Keywords: agroecosystems, agroecology, coffee production cost, full sun coffee, shade-grown coffee

1. Introduction

Coffee plantations covers 10,420,008 thousand hectares (Rudel et al., 2009), playing major role from economic to ecological perspective at global scale. In several coffee producer countries such as Brazil, Colombia, Venezuela, Costa Rica, Panama and Mexico, traditional cultivation of coffee is done under shading trees (Ricci et al., 2006). These shade-coffee plantations are considered biodiversity reservoirs, and yet serving for its productive end (Perfecto & Vandermeer, 2010). Agriculture intensification via tree removal and input use is known to reduce habitat extent and quality for native fauna. Intensification also promotes the decline in the provision of ecosystems services to coffee (such as pest control and pollination) (Goulart et al., 2012; Perfecto et al., 2004). This species loss may, therefore, reduce coffee production at long term (Goulart et al., 2012). The maintenance of those biodiversity rich ecosystems is largely depending upon the economic and productive viability for farmers.

Brazil is the world's major coffee producer, supplying one third of the worlds' coffee gross production (FAOSTAT, 2016). Despite of this, there are many knowledge gaps on many aspects of coffee production in Brazil, particularly regarding the shade influences. In 2014 national coffee production was 2712 million kg of benefited, being 70.5% of the total species *arabica* and 29.5% of the total species *Coffea canephora* (Brazilian Institute of Geography and Statistics [IBGE], 2014). Rondônia occupies the 5th place on the national ranking of coffee producers, being the second largest coffee producer of *Coffea canephora*, which corresponds to approximately 11.27% of the Brazilian production of coffee from group *Coffea canephora* (National Supply Company [CONAB], 2014).

Coffee is the most widespread perennial crop in the state of Rondônia, composing one of the main sources of income for many families in the countryside (Marcolan, 2009). Among agroecological systems, agroforestry stands out as an alternative for reconciling agricultural, social and environmental goals by combining crops with other backbone trees in forest-like agroecosystems (Nair, 1991). The cultivation of shade-grown coffee is an example of such management, which consists in shaded of coffee farms with native and exotics, crops and non-crops trees, having coffee as the main crop (Ferreira, 2005).

The effects of shade on coffee production are controversial and it may exert a positive effect by increasing soil quality, reducing climatic stress, and reduce weed invasion. On the other hand, low light incidence leads to low photosynthetic activity, and consequently less productivity. Therefore, shading should not exceed 30 to 40% of the entire agroecosystems (Mancuso, 2013). Perez et al. (1977) suggested that the removal of trees may increase in up to 30% productivity. According to Baggio et al. (1997), there is no difference between moderate shadow and full sun. Finally, other authors suggest that there is a ramped shaped relationship in which there is an increase of productivity with increase of shading up to a certain level, beyond which, a decline in productivity is observed (Soto-Pinto et al., 2000; Staveret et al., 2001). Therefore, cultivation of coffee may suffer favorable and unfavorable variations depending on shade level, soil and climate characteristics and management.

In Brazil, there is a great demand for assessing shading system in agronomic and economic terms, and there is scant quantitative information on shade effects in coffee systems (Perdoná, 2013). We here compared the productivity and production cost between shade and full sun systems of agroecological coffee *Coffea canephora* in the Brazilian Amazon. Furthermore, we draw the overall implications of our study to sustainability of coffee systems in the tropics.

2. Method

The study site is located in the Amazon Biome, in Padre Ezekiel settlement, in Mirante da Serra, Rondônia state, Brazil. The settlement is placed in the central region of the State of Rondônia, as shown in (Alves, 2010). The assessments were conducted in four properties with shaded coffee agroecosystem and four under full sun agroecosystems (Table 1). The data collection was carried out between June 2013 and June 2014 through visits to the crops accompanied by the farmers. The information were given by the farmers that agreed in participate in the survey and all activities occurred in this period were recorded, even if the researcher was not present. The shaded agroecosystems are formed of native vegetation left when the crops were implemented; therefore, the trees have the same age of the coffee crops. Backbone trees were composed of *Inga edulis*, *Tabebuia* ssp, *Bertholletia excels*, *Orbignya phalerata*, *Hymenaea courbaril*, *Musa paradisiaca* (banana trees), *Annona muricata*, *Caesalpinia equinata* and *Tabebuia cassiniodes*. Many areas were previously composed of pasture, which have been abandoned for deployment of coffee.

Crop management and the dates of the attainment were recorded (such as pruning, manual/mechanical thinning, mowing, harvest, drying and sale) in terms of working hours. The working costs analyzed here, only takes into account the operations in coffee plants without considering the depreciation of machinery, taxes and cost of land. We opt to assess only the costs related to the workforce due to the fact that it represents the major cost in coffee production. Cost of production is here defined as the sum of the values from all resources (inputs) and operations (services) used in a given productive process. For economic analysis purposes, cost of production is the compensation that production factors (land, labor and capital), use to produce determined goods. Production costs have been used to verify if resources employed in a production process are compensating, and enabling to check activity profitability (Viana & Silveira, 2009).

Table 1. Latitude, longitude and altitude of agroecosystems, total area, coffee plants interspacing and number of coffee plants

Agroecosystem	Latitude	Longitude	Altitude (m)	Total Area (ha)	Spacing between plants (m)	Number of plants
Shaded						
I	11º00'57.24"	62º37' 04"	252	1	3.5 × 3	952
II	11º01'44.34"	62º37'37.90"	228	1.5	3 × 3	1666
III	11º01'36.2"	62º37'02.1"	200	1.6	2.5 × 2, 2 × 5	2200
IV	11º01'08.5"	62º36'39.8"	236	0.27	3 × 3	300
Full Sun						
V	11º01'14.5"	62º36'43"	237	2.42	3 × 3	2688
VI	11º01'06.6"	62º36'27.1"	230	1	3 × 3	1111
VII	11º01'01.84"	62º36'41.22"	251	1	3 × 3	1111
VIII	11º01'07.21"	62º36'26.32"	228	1.5	3 × 3	1111

The values paid by labor to carrying out harvesting were calculated using the economic value of kg of processed coffee. There was no variation in labor costs between shaded and under full sun systems, because the values paid to harvest were equal per kg in all agroecosystems. The variations in production costs in this activity occurred only in accordance with the quantity (in kg of coffee per hectare) produced by agroecosystems.

Expenditure necessary for the production and cultivation related to the workforce detached for each activity were evaluated. *F test* (variance comparison) and t test ($\alpha = 0.05$) were performed to compare the average productivity per hectare between shaded and under full sun agroecosystems Kolmogorov-Smirnov tests were carried out to check for data normality distribution ($\alpha = 0.05$). The tests were performed using the Paleontological Statistics Software Package for Education and Date Analysis (PAST 2.04 for Windows).

3. Results

Full sun systems present higher production costs, accounting for more than twice the average of hours per hectare spent on shade systems in pruning and thinning activities (Table 2), while higher maximum average mowing hours were also found in full sun systems (Table 3).

Table 2. Frequency of activity, period and quantity of labor used in pruning and thinning

Agri.	Frequency	Period	Hours/per activity	Average hours/ha	Average hours/ha shaded and under full sun
Shaded					
I	1	August 2013	48	48	
II	2	July 2013	88	58.6	55.2
III	0	00	00	00	
IV	1	January 2014	16	59.2	
Full Sun					
V	2	Jan and FEB. 2014	256	105.7	
VI	2	Aug/Sep 13 Jan/Feb. 14	128	128	
VII	2	Jul/13 Feb 14	112	112	113,07
VIII	2	Jul/13 Jan 14	160	106.6	

Table 3. Frequency of mechanical/manual mowing and amount of labor hours required for the activity

Agroecosystem.	Area (ha)	Frequency	Date	Hours	Average h/ha
Shaded					
I	1	3.0	Nov 2013/Feb and May 2014	72.0	72
II	1.5	1.0	April 2014	12.0	8.0
III	1.6	2.0 Manual	June 2013	96.0	49.2
		1.0 Mechanical	May 2014	24.0	
IV	0.27	1.0	March 2014	8.0	29.6
Full Sun					
V	2.42	2.0	Oct 2013/Mar 2014	128,0	52.8
VI	1	3.0	Jul 2013/nov2013/Feb/2014	96.0	96.0
VII	1	2.0	Oct/13 and March/14	72.0	72.0
VII	1.5	2.0	Sep./13, Feb. and Mar/14	88.0	58.6

The activity of drying were carried in farm and using a drier. Coffee beans were dried in the property, performed outdoors, bare soil or using direct fire dryers placed in the municipality of Mirante da Serra. Coffee grains produced by agroecosystem II the coffee were marketed mature, the sale was conducted without drying. Drying in the dryer was only performed for coffee produced in agroecosystem VI and represented 6.5% of the value obtained with the marketing of the kg of coffee.

The table below (Table 4) shows that the average productivity per hectare in shaded agroecosystems suffered the greatest variation when compared to productivity of under full sun agroecosystems.

Table 4. Harvest period, number of kg per hectare per agroecosystems, value paid for harvesting and total cost.

Agroecos.	Harvest Period	Kg per hectare	Kg per agrieco.	Value of the kg/US$ for harvesting	Cost of harvesting US$
Shaded					
I	May and June 2014	1260,00	1260,00	0,28	355,69
II	April and May 2014	499,80	750.00	0,28	210.00
III	April and May 2014	750.00	1200,00	0,28	336,00
IV	May 2014	2221,80	600.00	0,28	168.00
Full Sun					
V	April and May 2014	618,00	1500.00	0,28	420.00
VI	April and May 2014	870,00	870,00	0,28	242,60
VII	April and May	960,00	960,00	0,28	268,80
VIII	April and May 2014	920,00	1380,00	0,28	386,40

Table 5 provides a synthesis of agroecosystems production, total production by agroecosystems and average per hectare.

Table 5. Total production, production and average production of shaded and full sun agroecosystems

Agri.	Total production (kg)	Production (kg)	Production (kg) average per hectare of shaded and unshaded agroecosystems
Shaded Coffee			
I	1260,00	1260,00	
II	750,00	499,80	1.182,45
III	1200,00	750,00	
IV	600,00	2220,00	
Full Sunlight			
V	1500,00	619,00	
VI	870,00	870,00	842,25
VII	960,00	960,00	
VIII	1380,00	920,00	

The variation of sale values (US$) per kg of coffee occurred in accordance with the period in which this had been marketed. For this reason, the prices of kg of coffee between April and July ranged from US$ 0.882 to US$ 0.952, and between October and December, the price ranged from US$ 0.98 to US$ 1. 064.

Shaded agroecosystems (I, II, III and IV) presented a lower frequency in crop handling reflected in the decrease in required labor quantity (h) for the activities performed in the agroecosystems under full sun. This occurred mainly due to tree species in the agroecosystems, which increased the shade to coffee plants and altered the spontaneous weed populations, reducing competition.

The agroecosystems under full sunlight showed low variation in productivity (standard deviation SD = 153.31 and variation coefficient VC = 18.20 %), while variation was significantly higher in shaded agroecosystems, (standard deviation SD = 760.60 and variation coefficient VC = 64.32%). In agroecosystems under full sun, cultivation also came with small differentiation in total cost of production (88.30% and 78.45% 94.60% and 67.45%). The possible causes of similarity in production may be due to crops being conducted with the same crop handling. The systems under full sun are more homogeneous, presenting low differentiation amongst the agroecosystems themselves. The costs with the workforce in under full sun systems were higher compared to shaded crops (Tables 6 and 7) due to the absence of the woodland component (tree layer) , which inhibits the incidence of direct light in cultivation and consequently reduces the need for time in labor to suppress weed.

Table 6. Production cost per activity (pruning and thinning, mowing and weed suppression, harvest, drying), total cost and net margin in percentage of the cost required per activity

Agrecossytem	Pruning and thinning	Mowing	Harvesting	Drying	Total cost of production	Net Margin
Shaded						
I	6.20%	16.30%	28.50%	4,13%	55.13%	44.87%
II	20.00%	4.8%	30%	00	54.80%	45.20%
III	00	17.11%	26%	2.97%	46.08%	53.86%
IV	4.56%	4.0%	30%	6.84%	45.4%	54.6%
Full Sun						
V	29.10%	25.60%	30%	3.60%	88.30%	11.70%
VI	25%	33.10%	30%	6.5%	94.60%	5.40%
VII	29.41%	12.65%	29.41%	6.98%	78.45%	21.55%
VIII	26.31$	9.56%	26.31%	5.27%	67.45%	32.55%

Table 7. Total Cost, gross income, percentage and net margin per agroecosystem

Agri.	Workforce total cost US$	Total gross income in US$	Net Percentage	Net margin in R$
Shaded				
Agri. I	686.53	1245.30	44.87%	558.76
Agri. II	212.72	470.63	45.20%	257.90
Agri. III	374.58	811.84	53,86%	437.26
Agri. IV	260.55	564.76	54.6%	304.20
Full Sun				
Agri. V	515.17	583.43	11.70%	68.26
Agri. VI	774.67	818.90	5.40%	44.22
Agri. VII	723.06	921.70	21.55%	198.62
Agri. VIII	665.88	987.20	32.55%	321.33

The data on productivity presented a normal distribution ($p = 0.53$). The differences between the variances was significant ($F = 24.6$, $p = 0.02$), and considering unequal variances, we compared the averages using the t test for unequal variances (Welch test), which showed no significant differences between the productivity in the different agroecosystems ($p = 0.44$). Thus, the raw values are higher in shaded agroecosystems, however, differences were not statistically significant, due to the large amplitude in average productivity among shaded agroecosystems (499.8-2222.22 kg/ha).

4. Discussion

The results of this research indicate that the shaded agroecological systems presented higher economical results than cultivation under full sun, because it requires less working hours. Systems under full sun have smaller variation in productivity than shaded intercropping; possibly due to the fact that full sun agroecosystems are more homogeneous among themselves, while shade agroecosystems are much more heterogeneous. Another possible cause of high variation in shaded agroecosystems is area variation in the shade systems. For instance, agroecosystem IV presented a small area (0.27 ha) and presenting the highest productivity (2222.22 kg/ha). The conversion of the value of total production (0.27 ha) in production per hectare may have overestimated the value of average systems productivity. The negative relationship between farm size and productivity is long known in the agricultural sciences, and smaller farms are more easily and effectively management and thus produce more than larger counterparts (Rosset, 1999).

Some studies show an increase of 10% to 30% in coffee productivity with the removal of trees (Perez, 1977). Baggio et al. (1997) show that there is no difference between moderate shade and full sun. Finally, other authors suggest that there is productivity increase with shading up to a certain level, beyond which, a decline in productivity takes place (Soto-Pinto et al., 2000; Staveret et al., 2001). In a revision paper, Damatta (2004) concludes that the productivity in shaded systems is superior in comparison to crops under full sun in situations in which the edaphic conditions are sub-optimal. Shading agroforestry is also known for reducing the impact of frosts (Baggio et al., 1997) and water stress on the events of drought (Damatta, 2004). Moreover, in cultivations under full sun that are more than one or two decades old, the quality of the soil is committed, thus there is lower productivity compared to shaded systems (Damatta, 2004).

We did not find significant statistical differences in the productivity of shaded versus full sun systems, although raw values suggested higher performance of shaded systems. Lower variation in productivity was found in full sun systems, possibility due to complexity and heterogeneity of shaded systems in comparison with the former. The combination of different shade degrees, agriculture design, backbone tree composition, farm size and other management variations may greatly increase shade system variability.

Full sun systems are more labor intensive than shade counterparts, due to the greater frequency and time spend per activity of pruning, thinning and mowing for weed suppression. Due to less light incidence in shaded agroecossytems, weed invasion is reduced and coffee plants show lower sprouting, easing the systems management. For Mancuso (2013), shading can modify the composition of weed species, reducing the number of most competitive plants. Weed invasion drops to very low levels in systems with more than 40% of shade (Mancuso, 2013). Other positive effects of shading are the increase of organic matter, edaphic fauna enrichment, and increase in nutrient cycling, reduction of soil erosion, biodiversity conservation, and attenuation of extreme temperature and wind incidence (Mancuso, 2013). Furthermore, productive lifespan of shaded coffee is longer than plants under full sunlight (Damatta, 2004).

Back-bone trees promote changes in energy distribution, in thermal air conditions, soil and in the coffee plants which presents differentiated growth. Plant´s stress reduction by the improvement of microclimate and soil quality (Lemos, 2007). Additionally, shading with appropriate tree species produces larger fruits, with softer and sweetened tissues, improves vegetative aspect of coffee, increase in the number of primary and secondary branches, increasing reproductive capacity of coffee trees (Lemos, 2007).

Intermediate levels of shade are known to alleviate extreme climatic conditions in *Coffea canephora* providing greater sustainability to the systems (Damatta, 2004). Back bone trees also adds to the productive potential for the shaded systems, providing extra income for growers due to production of wood, fruits, medicinal plants, herbs and essential oils, fuel and fiber (Pezzopane et al., 2007; Coelho, 2010). These additional crops can be harvested during the periods between coffee harvests, securing a more constant income source for famers. Furthermore, shade systems may also contribute for better working conditions, protecting farmers from direct solar radiation, promoting health and wellbeing (Mangabeira, 2009). Also, shade coffee certification can increase coffee price in markets, due to its ecological and social benefits. Fair trade, shade coffee, organic is example of agriculture certification which is growing around the world, increasing the economic return of the agroforestry products (Perfecto et al., 2005).

By and large, the cultivation of shaded coffee *Coffea canephora* presented higher performance than full sun, due to less workforce requirements, enabling extra-income from associated crops, contributing to farms wellbeing and biodiversity conservation, although shade systems present very high variation in productivity in the Amazon. Many other tropical landscapes may share similarities with this environment and thus may present similar trends in terms of shade effect on coffee production. Much of the tropical farmers are small holders, owing properties not larger than two hectares (Lowder et al., 2014). These farmers are mainly economically poor population particularly susceptible to price elasticity of agriculture inputs. Our results corroborates with the high productive efficiency of shaded coffee, being a viable alternative and environmental friendly practice in the tropical region.

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