MASTER THESIS

The influence of canopied coffee on outcome and biodiversity aspects - a case study in El Cairo in Colombia

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Abstract

The rapid expansion of the worldwide coffee production in the 1970s led to modifications of the growing systems in Colombia. From traditional canopied coffee, the trend moved towards sun grown management with higher yields expectations, implying deforesting and loss in biodiversity. For the connection between economic and environmental objectives, this paper analyses the influence from different canopy levels on the production outcome within a case study in El Cairo, Colombia. Furthermore, biodiversity aspects are combined with the statistical results to illustrate losses in yields for different ecological goals.

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1 Introduction

Shaded coffee certification started to raise in the 1990s as a reaction on the trend of conversion from traditional canopied coffee to sun-grown monoculture with high fertilizer input. Driven by higher crop productivity expections through monoculture management within an increasing global coffee production, the producers reduced the canopy level, which describes the resulting shadow area from trees over the coffee bushes expressed in percent value (Mas and Dietsch, 2004; Lambot et al., 2017).

Between 1970 and 1990 the production worldwide expanded by 58%, whereby Colombia belonged besides Brazil and Indonesia to the three most producing countries. In Colombia, the change to lower-canopy systems even increased by 60% (Shalene et al., 2014). As a consequence of deforesting of shadow trees, the biodiversity decreased both for animals and trees. To counteract the resulting negative environmental effects, shaded certification programs started promoting the additional ecological service of canopied coffee (Mas and Dietsch, 2004; Lambot et al., 2017; Beenhouwer et al., 2013).

There are different views about the influence from shaded coffee on the production outcome of coffee beans. On the one hand the lower light supply through shadow trees in comparison with sun-grown coffee leads to a less photosynthetically active coffee plant, which results in an increasing output, if canopy becomes reduced. But on the other hand, the deforesting of shadow trees means a higher risk for pest and disease, whereby the output might diminish (Alves et al., 2016; DaMatta, 2004). Although of the prevailing disagreement about the influence from shadow trees on the outcome, many producers justify canopy reductions with the expectation of higher yields (Shalene et al., 2014).

While previous researches focus more on differences between sun-grown and canopied coffee with controversial results about the influences of output and biodiversity, the research in the field of canopied certificated coffee is rarely explored.

This thesis analyses the influence from different canopy levels on the production outcome within a case study in El Cairo, Colombia. Eighteen coffee farms with various shadow were used as study plots for the research. For the coffee producers which are already part of certificated shadow coffee system (and hence already decided to grow canopied coffee), it could be interesting to know the optimal canopy level within the certification requirements, to maximize their outcome. In this way, they still get the certification premium and combine sustainable with economic interests.

For the certification organizations, this work can be considered as an approach to fairly compensate the coffee producer by different price premiums, based on the varying outcomes for the respective canopy levels.

If certification organizations want to motivate participating producer to increase their canopy level (for example for environmental improving reasons), the thesis provides a method to find the optimal premium, adjusted for the losses in production outcome, required that producers really have lower outcomes for higher canopy levels.

El Cairo is a community presenting several small villages with overall almost 10,000 inhabitants and belongs to the province *Valle de Cauca* in the western part of Colombia. As part of the Andes region it is located in a hilly landscape. Like in many rural regions of Colombia, the economy consists mainly of growing coffee, plantain, sugar, maize and fruits (Cairo, 2017). The coffee producers are connected in the centrally-located organization *Serraniagua* for mutual support and to work together with different research programs. One important cooperation partner is the *Klimabündnis* in Vorarlberg, Austria, which promotes ecological protection. Until now, the coffee producers just sell their coffee in the center or the small villages around El Cairo, although they meet the conditions for being part of an international certification system. Besides *Serraniagua* there is a collaboration of engineers working together for continuous improvement of coffee growing management, called the *Federación Nacional de cafeteros*. Their objective is the connection of efficiency with sustainability through investigation of the effects of different growing strategies. They own both canopied and sun grown coffee plantations for performing comparisons and to find the optimal coffee management.

Section two provides information about the coffee production, including the various possibilities of growing coffee, differing in ecological aspects and management intensities. The historical development of the coffee production in Colombia is characterized by an emergence crisis as trigger for the trend of reducing shadow trees. To get a deeper understanding about the study site, I describe further details about Colombia's coffee economy and El Cairo.

The third section illustrates a short literature review about the establishment of price premiums for certificated coffee and the different programs. Further, the problems for reaching a fair and feasible certification mechanism are addressed. Previous papers about canopied coffee and the influence of the production outcome are presented and show the need on further research in this field.

In section four I set my hypothesis about the influence of canopied coffee on the outcome, before I describe the data acquisition. I collected data about the size, the sea level and the outcome per year for the 18 coffee plantations in El Cairo. Additionaly, I determined the canopy level through a combination of two different measurement methods. All plantations produce shadow coffee and were checked for fulfilling the requirements of a certification program, so that they could theoretically sell their labelled coffee on the international market. Subsequently follows the statistical analysis, whereby I examined the influence from the canopy level on the production outcome for the study plots. Therefore I applied a regression analysis with the size and the sea level as control variables.

Section five outlines the results. The simple regression analysis with outcome as explained variable, canopy as explaining variable and sea level and size of the coffee plantation as control variables, shows no significant relationship. The same applies for the quadratic model. Finally, with the cubic regression there is a statistically significant correlation. In the graphical representation it becomes apparent, that the outcome rises for increasing canopy for lower shadow up to a peak point around 40%. Afterwards, increasing canopy leads to a fall in outcome and stays then consistent for high shadow levels with small variations.

Focusing just on the economic point of view, most of the coffee producer could increase their income by reducing canopy. For the organizations' perspective this means a need of higher premium as a compensation for more shadow, if they want to raise incentive for ecological conservation. The data from the study plots and price information are used to calculate the yield differences for various canopy levels.

In addition, section six considers the biodiversity of bird species richness, influenced by differend canopied systems, through involving external data from different studies in South America (Philpott et al., 2008). The results of the, show broadly a positive influence on biodiversity for systems with high canopy. For the integration of the external data, the study plots in El Cairo were organized into the growing systems and pictured with their respective outcome losses for pointing out the interaction between economical and biodiversity aspects.

The conclusion in section seven finally refers to limits and further possible expansions of the study.

2 Coffee production

2.1 Agricultural systems

The basic different practices for coffee production are the forestry, the conventional agricultural and the agroforestry. Whereas the rather unshaded conventional system is not very sustainable due to the application of chemical products and deforestation, the agroforestry enhances an efficient use of the resources and is rated as environmental friendly. There are different forms of agroforestry, depending on the canopy level and the species management (Jose and Gordon, 2008, pp.3–4).

The arrangement of the shadow trees can either be mixed, which means there is no strict order of coffee trees and shadow trees, or in the case of a zonal arrangement, there are different opportunities for a systematically formation of the trees. Furthermore, the disposition indicates about the species diversity. There can be different species with various strata or there is just one coverage height (Farfán V., 2007).

2.1.1 The five different agroforestry systems

Moguel and Toledo (1999, pp.12–14) differ between five forms of growing systems related to the shadow, the tree species richness and their average height (figure 2.1). The *Rustic* system has the highest shadow level and is established through the cultivation of coffee trees under an existing forest, so that only the lowest area is removed. For this system, normally there is no need for chemical products and it is assumed to be the best way of maintaining the biodiversity, but the production of coffee is expected to be at a very low level, which can result in a small yield for the producers.

For this reason, the *Traditional Polyculture* is more popular for shaded coffee systems, whereby the coffee is still grown under plants with a shadow level usually higher than 60%, but there is a mixture between native and implanted plants, which are also useful for production (for example fruit trees or medical plants). This system leads to higher expected outcome than the *Rustic* system, but still has a good influence on the biodiversity and normally does not need chemical products.

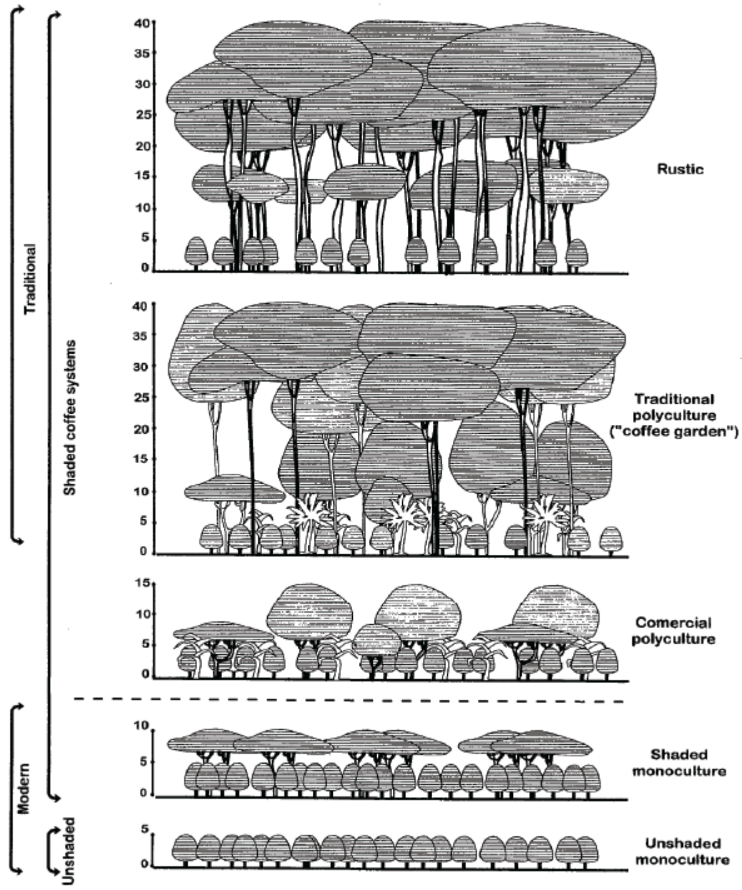

Figure 2.1: The five coffee-growing systems, source: Moguel and Toledo (1999)

In the case of the *Commercial Polyculture*, a lot of native trees are removed through implanted shadow trees and the canopied area is between 31% and 60%. The implanted trees are specially chosen for the coffee cultivation, so that they supply the coffee output, but chemical products may be necessary.

The *Shaded Monoculture* is similar, but normally only includes one species of shadow trees with canopy cover under 30%. The whole cultivation is based on a market-oriented production for an almost higher output than the other canopied systems. In this case it is obligatory to use chemical products.

For the *Unshaded Monoculture* form, there is no tree cover left, whereby it also could be considered as an agricultural system. It needs a lot of chemical products and high working effort for the cultivation, but also is expected to give the highest possible output to the producers. It is also assumed to have the most negative influences on the ecological system.

2.1.2 The management systems

There are four main forms of coffee plantation management depending on the intensity, which describes the inputs and the vegetative structure complexity (the composition of shading trees). The management intensification is strongly linked with the quantity of shadow trees and the canopy cover (Shalene et al., 2014). Jezeer and Verweij (2015) provide a differentiation of the systems:

The *Traditional System* has the lowest canopy level and also a low management intensity, which leads to a low density of coffee trees. In this case the producers often have no access to inputs and hence use just small amounts of both organic and chemical applications. In contrast, the *Conventional System* is determined by a huge input of organically and chemical products for a high coffee tree density. But the canopy level is rather low and the diversity of shade trees is very poor. Resulting from this low biodiversity-friendly cultivation, most of the farms are not certified. The *Shaded Intensified System* illustrates both a high density of shade trees and a high intensity level. Consequently, producers of this system normally make use of organically and chemical input, but the latter one with restriction. The main share of this coffee production is part of a certification system. The highest canopy level is reached by the *Shade Organic System* with a great vegetative structure complexity. Concurrently the management intensity is weak, which means the producers of this system typically just use organic input. Therefore, most of them are certified. Both the *Shaded Intensified System* and the *Shade Organic System* can be classified as *Rustic* system but differ for the usage of fertilizer.

2.2 Historical changes and trends of production

Already in the 19th century was the coffee production one of the most exported crops in Colombia and covered a huge part of the agricultural labor. Traditionally the coffee was cultivated under diversity shade (Perfecto and Armbrecht, 2003; Perfecto et al., 2005). In the 1970s arose a tendency - driven by a coffee leaf rust crisis in Central America and Brazil - for reducing shade and using chemicals products for intensive coffee crop management and higher yields. This trend became a problem for small producers, which had no access to chemical fertilizers. A counter movement, based on urban consumers, started to support organic coffee (Vossen, 2005; Perfecto and Armbrecht, 2003; Gobbi, 2000). Between 1970 and 1990 around 60% of the coffee plantation in Colombia changed from traditional canopy systems to lower-shade management (Shalene et al., 2014). An occurring coffee epidemic in Colombia and the Civil War in South America in the 1990s resulted in falling coffee prices and decreasing production (Perfecto and Armbrecht, 2003; Avelino et al., 2015). At the same time the world coffee market was floated by Vietnam with cheap prices. Therefore, a global overproduction followed and the lowest coffee prices in 2001 for 30 years. The consequences were ongoing shade reduction, loss of biodiversity and soil degradation to keep up with the strong international competition (Souza et al., 2012; Gobbi, 2000). Many small producers in Colombia had to leave their plantations, because of the price erosion. This resulted in unemployment, poverty and migration flows to the United States (Perfecto and Armbrecht, 2003).

Colombia could not really recover from that crisis, because already between 2008 and 2011 a leaf disease, called *Coffee rust*, spread over the country and led to a decline in coffee production by 31%, compared to the year 2007. The crisis was triggered by the previous drop in prices and the followed saving measures in the cultivation management. Additionally, more extreme temperatures as a consequence of climate change had a negative influence on the crop (Avelino et al., 2015). Meanwhile there are various studies about the connection between coffee cultivation and environmental protection, supporting management systems with high canopy level (Perfecto and Armbrecht, 2003; Beenhouwer et al., 2013; Faminow and Rodriguez, 2001).

2.3 The study site

The Colombian economy largely depends on Arabica coffee production. For the years 2012/13 Colombia exported about 594 million kg of green beans. The forecasts made for 2016/17 were already about 870 million kg and for 2017/18 about 876 million kg (because of the high effort of data procurement, there are not yet exact information available). Colombia is on the second place directly after Brazil regarding to the worldwide Arabica coffee export and holds the third place overall, replaced from the high export amount of Robust coffee in Vietnam. The main part of the Colombian export is demanded by the US with 40%, followed by the EU, Japan and Canada. In comparison with the last decade, the average productivity of coffee in Colombia is 29% higher, which is assumed to be the result of replanting programs with more resistant coffee trees for *Coffee rust* and higher plant density (USDA, 2016; Rau and Conlon, 2017).

With 936.682 ha, at least about 8.2% of the whole country area is utilized for the coffee production (FNC, 2013). Most of it is cultivated by small producers with an average plantation size of 4.5 ha. Since 2013/14 the international coffee prices are usually over the break-even point (interrupted from two short crashes) and reached 2016 the highest point in this period (Rau and Conlon, 2017).

To counteract the mentioned cultivation trend of sun grown coffee in Colombia, several certification programs for protecting the environment were established in the last years. More than 40% of the exported coffee counts as *Specialty Coffee* ans is therefore labelled with certifications. A major challenge is posted by the climate change and its uncertain influence on the coffee crops. The weather phenomenon *La Niña* in 2016, which is assumed as consequence of the climate change, resulted in substantial outcome reduction of the coffee production (Giraldo R. et al., 2009; Rau and Conlon, 2017; Gaitán et al., 2016, pp.5–8).

El Cairo lies 1850 m above sea level. From the about 10,000 inhabitants, just about 3,000 live in the center, the others are mostly farm owners distributed around the area with 283 km^2. The center village El Cairo and its surrounding are part of the *Coffee Cultural Landscape of Colombia* as an *Unesco world heritage*. The special mountain conditions require a certain adaption of the cultivation for the coffee farmers. For maintaining this world heritage, the *Columbian Coffee Growers Federation* established an institutional network to integrate the different stakeholders in one concept and offer support for the 85.850 membership families. Through developed sales strategies of organic coffee, it is possible to give the coffee producer financial backing, because the adapted crop crowing in the cultivated landscape is said to be very costly in comparison with the traditional method (Unesco, 2017).

In El Cairo the corporation *Serraniagua* was founded in 1996 to connect the producer and the local population. The aims of the organization are the environmental protection, the promotion of the production process of coffee, sugar and cocoa and the encouragement of the local population to raise their power. There are more than 60 reserves part of *Serraniagua*, whereby most of them are managed of communities. Also, the touristic sector, schools and environmental groups are supported by the organization. The basic idea is to use the accumulated power of the different stakeholders through working together and to give small land owners a voice in political decision-making process. Many scientists from local universities perform their research within the ecosystems in El Cairo, to experience effects of sustainable growing techniques (Lamptey et al., 2012).

3 Literature Review

3.1 Price Premium

Coffee certifications are used to provide information for the consumers and to promote changes in the society's purchase behavior. Besides, they are targeted on an incentive for both the policy and the producers to act more sustainably. To improve the production process, at first the consumers' willingness to pay a premium for ecological protection is needed. Although the aims of the programs are in most instances very similar, there are a lot of different certification logos for the coffee market with diverse conditions (Galarraga and Markandya, 2004, 2006).

From a theoretical economic point of view, the certification program poses an approach to internalize the external effects of the coffee cultivation for the environment. Through a premium for environmental supporting conditions, the producers obtain a compensation for their additional service, which results in positive external effects. Within the certification process the organizations usually determine specific standards concerning the issues labor, environment and production. Sometimes also the political structure is part of the contract (Perfecto et al., 2005; Haight, 2011).

The certification programs can become broadly divided into the fair traded, the organic and the shaded grown coffee, which has the smallest part with 10.5%. This is caused by the fact, that canopied coffee is often also part of the organic coffee requirements. Its program refers to the production of coffee under a sustainable management without using chemical synthetic products and special quality conditions (Perfecto et al., 2005; Valencia, 2007, p.244).

Also, fair trade and organic coffee are strongly linked. Most of the fair-traded coffee fulfil simultaneously the organic condition, hence they are often both sold under the *Fair Trade* logo. Because there is no general international market including a unified structure for certificated coffee, the distribution and the allocation of certifications as well as the determination of the premium is managed from the organizations (Galarraga and Markandya, 2006).

Observable data illustrate a trend of contrary behavior of the premium price for certificated coffee to the relative price of the regular coffee market (without certifications). This means, that a decrease in regular coffee price seems to be linked with a relative increase of the premiums and vice versa. Explanations can be found in the premium specification of the organizations. The *International Fair Trade Labelling Organization* (FLO) for example defines a minimum price of 3.09 USD and a premium of 0.44 USD per kg (status of 2014), which hold for *Fair Trade* coffee, if the regular world market price is lower. If it is higher, the price automatically rises to the respective amount (Gobbi, 2000; Dragusanu and Nunn, 2014). For the shaded coffee, the premiums in 2006 accounted for between 0.22 USD and 1.33 USD per kg (Perfecto et al., 2005). According to a survey from 2002, certified coffee (which includes also shade-grown coffee) is supported in general with a premium between 1.17 USD and 1.37 USD per kg (Commission for Environmental Cooperation, 2016).

3.1.1 Programs

The *Fair Trade* coffee in Europe, Japan, United States and Canada is sold under the FLO since 1991. It represents minimum prices, covering at least the costs of production for environmental protection through organic coffee cultivation. The two main strategies of the FLO consist of paying a price premium for further investments in the production process and the elimination of intermediaries. Additionally, the coffee producers obtain prepayments for the financing. Besides the social and economic support, the FLO program pushes on democratic development through appropriate conditions in the contracts with the producers and their society. The organization especially supports small producer with international connections to establish themselves in the commercial business under fair prices. Moreover, the FLO aids the plantation workers through prohibition of child labor and healthy working conditions (Galarraga and Markandya, 2006; Valencia, 2007, pp.242–243).

A great part of the certified shaded coffee is sold under the generic term *Biodiversity-friendly Coffee*, with special developed criteria by the *Ministry of Environment and Natural Resources*. Amongst others conditions it determines the canopy cover level at least of 40% and the minimum number of different native tree species at ten. In addition, the ministry codified special cultivation practices for the protection of forests and the soil and also forbids hunting and the usage of high-toxic pesticides. The workers of the respective farms have to participate on trainings for using agrochemicals (Gobbi, 2000).

An own certification for biodiversity-friendly coffee and hence a significant part of shaded coffee is sold under the *Bird Friendly* logo, founded by the *Smithsonian Migratory*

Bird Centre in 1998. The institution operates investigations about the influence of coffee cultivation management on migratory birds. Its corresponding coffee is organic, grown under canopy and has to fulfil environmental standards. With the taken money from the premium the institution funds investigations and invests in the education of both producers and consumers.

To reach also the consumers of usual supermarkets, the certification program *Eurep GAP* includes big chains in Europe for the distribution of its coffee with certain requirements of the production and quality standards. Part of its strategy is a voluntary control system of the production conditions (Valencia, 2007, pp.243–244).

The *Red de Agricultura Sostenible* (RAS) pools several independent organizations to support the sustainable production of coffee and appropriate standards. Every participating organization has to pass the common developed know-how and experiences of the coalition RAS along to its producers. The strategy of the RAS is to plan, implement and observe sustainable production practices. Part of it is the *Rainforest Alliance*, which cares for the administration of the RAS and certifies canopied coffee under the *Eco-OK* label (Perfecto et al., 2005; Valencia, 2007, p.242).

In Colombia there are various certification programs to assist particular the farmers and the environment. As a main organization, the *Superintendencia de Industria y Comercio* verifies all certifications distributed in the country. In the end of the 1980s the group *Cafés especiales de Colombia* was founded with arising subgroups under its guidance. These subgroups have their own certifications differing in their key aspects. One of them for example is the sustainable coffee, which in turn includes the organic, bird friendly and fair-traded coffee. The popular coffee chain *Juan Valdez* facilitates environmental and fair produced coffee of Colombia through distribution in its coffee houses and the international market system (Valencia, 2007, pp.240–245).

3.1.2 Problems of the certification systems

Whereas the concept behind the certification system sounds promising as solution to internalize the positive external effects of environmental friendly coffee production, participants complain about a not working certification process.

It is difficult to assess the value of resulting losses for the producers of labelled coffee, because in different locations the effort for environmental friendly coffee cultivation (including the expected outcome difference) can vary, so in some cases the premiums do not cover all additional costs. This might lead to less motivation for sustainable cultivation, especially if producers are afraid of competitive losses through higher investments compared to the regular coffee (Galarraga and Markandya, 2004; Perfecto et al., 2005).

Data from the *Rabobank International* examined a division of the selling price for regular coffee, where retailer obtain about 13% and producer 26%. In the case of certified coffee, retailer receive 20% and producer 27% (status 2006). The results show, that the relative margin for retailers is higher than for producers, if they change from regular to certified coffee and this is also valid for the absolute values. For the consumer this could give the impression of an unjust distribution of the price premium (Galarraga and Markandya, 2006).

Partially the conditions of the programs signify big interferences, for example through dictating the farm size or democratic organizations in their society. Some certification organizations do not transmit the premium directly to the producers, but invest it instead in collective usage, like the education system. This seems to be beneficial for the whole economic development but reduces the motivation of the producers.

Even in the case, that the producers obtain the premium directly, the workers on the farm are often still excluded from the benefits (Haight, 2011; Perfecto et al., 2005). The investigation of Dragusanu and Nunn (2014) in Costa Rica confirmed, that there is no influence from certified *Fair Trade* coffee on the workers income. Rather there could be proved a negative relation between *Fair Trade* coffee and their children's education, because the higher income of the producers through the premium seems to be an incentive for them to leave school early for working in the coffee business.

Further, the producers usually have to pay for the whole process to get the certification, like the inspections and the registration. This means a high effort before they gain the premium and some producers might even not be able to pay for the procedure. Therefore, the incentive for cultivation environmental friendly coffee becomes threatened (Vossen, 2005).

Small producers tend to cultivate coffee under management systems with high canopy cover, even if they would expect higher yields for less shadow, because they cannot afford the high costs for chemical inputs and pest control, which are necessary for intensive *Monoculture Shade*. Thereby they have a disadvantage towards more wealthy owners for making the decision and need to be supported for this inequality apart from their higher environmental service (Faminow and Rodriguez, 2001).

Another problem is concerning the quality. For the traditional coffee there are several quality levels, which account for the price differences. In contrast, for the system of certified coffee there is usually no focus on the various quality levels, but just on the fulfilment of the conditions. Hence if the producers sell their coffee both in the regular and the certification system (which is quite common regarding the small demand for environmental friendly coffee) they tend to use their high-grade coffee for the regular market and their lower quality coffee for the certification distribution to maximize their profits. Consequently, the consumers of certified coffee, which in general pay a higher price, run the risk of getting the lower quality compared with the regular coffee consumers (Perfecto et al., 2005).

Focusing on the consumers' perspective, the large offer of certifications can lead to confusion. Especially because the law does not improve the situation, resulting in unprotected terms like *green* and *organic*, this increases consumers' distrust in labelled products. The additional lack of transparency about the production process and the certification program induces misleading consumers with wrong perceptions and interpretations. Accordingly, this could lead to a decreasing motivation of buying certified products. On the other hand, the desirable effect of an increasing demand for certificated products might also support non-sustainable products, if big companies invest the additional money through the premiums also for their environmental damaging products (Galarraga and Markandya, 2004).

Canopied coffee includes diverse forms of shaded growth including light intensive management with only one type of shadow trees, that is accepted in some organizations as certificated shaded cultivation, although it is not delivering a positive contribution for biodiversity. There are different opinions about the term shaded coffee and various certification approaches. Some certifications just include the so called *Rustic System* with high canopy levels as shaded coffee, others also pay a premium for *Monoculture System* with small shade, which is according to several studies not environmental friendly. Hence their producers might get the same premium as others with higher shadow levels and more effort (Kricher, 2011; Perfecto et al., 2005, p.494).

Most certification programs do not include the economical aspect considering the effects on the yields but focus only on the environmental subject. This increases the threat of an inefficient price premium and hence a dead weight loss. A suboptimal price premium can encourage producers to stay in the coffee business, even if the plantation together with their cultivation management is not suitable for it (Haight, 2011; Perfecto et al., 2005).

3.2 Canopied coffee and the output

The influence of canopy on the outcome for the coffee production is controversial in the previous research. Where some works support the view of a negative effect (Rice, 2010; Schmitt and Grote, 2006), some think of a positive one (Escalante, 1995) and others consider the relationship between canopy and outcome as complex function (Perfecto et al., 2005; Staver et al., 2001; Alemu, 2015).

There are biological explentations for every statement. Losses in outcome through increasing the canopy level could result from a weaker photosynthesis based on lower sun light. Consequently, the stimulus on the buds falls, so that the coffee tree produces fewer nodes per branch and also less flower buds at the existing nodes. These amount of flower buds are responsible for the number of coffee beans.

On the other hand, too much sun-light can lead to overbearing, whereby the coffee tree is threatened to become exhausted which would result in a decreasing production for the following bloom. In this way, the sun grown coffee runs the risk of an irregular production outcome (DaMatta, 2004).

Previous work does not provide a lot of researches about influences from shadow levels on the outcome within canopied coffee. Most of them focus on the differences between canopied and sun grown coffee (Muschler, 1997; Alemu, 2015; Baggio et al., 1997).

Perfecto et al. (2000) analyzed the effects of shaded coffee on the yield and also the influence of the altitude. Therefore, they investigated in 36 study plots in Mexico with shade between 23% and 70% and figured out a quadratic function describing the relationship. But no information about certifications of the coffee from the study plots is available.

In the study of Shalene et al. (2014), the research outcome is a single peaked function as relationship between shadow and outcome, whereby the maximum was reached between 35% and 50% canopy cover.

The research of Escalante (1995) shows other results. He interviewed 120 farmers with all producing canopied coffee in Venezuela and collected data about the density of the shadow trees. Generally, the coffee yields decreased almost proportionally for an increasing number of shadow trees per ha.

4 Methods

4.1 Hypothesis

Based on the prevailing opinion according to many coffee producers in El Cairo and the economically driven trend for reducing shadow, it is expected that lower canopy leads to higher outcome.

That would mean that producers, who are participating in a certified coffee system, should always choose the smallest possible canopy level, which still meets requirements to obtain the certification premium. Therefore, the hypothesis results, that within the requirements of canopied coffee, higher shadow level lead to less production outcome. The biological explanation of shadow thwarting the photosynthesis underpins the hypothesis of lowest possible canopy level as outcome maximizing strategy. But it has to be considered, that overbearing through high sun light can lead to a counter-effect.

4.2 Requirements of shadow certification

Depending on the program the farmers have to fulfil several requirements to get the certification. In the field of canopy coffee this includes of course a minimum shadow level but can also imply other conditions.

The *Rainforest Alliance* certification requires at least 40% canopy cover and 12 native tree species per hectare used as shadow trees. Not all of the farms would fulfil these conditions concerning the canopy minimum. But the *Rainforest Alliance* is also part of the *Sustainable Agriculture Network*, which developed the *Sustainable Agriculture Standards* (SAN). Hence the producer can either meet the firstly mentioned requirements or the SAN conditions to get the certification of the *Rainforest Alliance*. The SAN contract is based on five principles, which are embedded in a system, where the farms do not have to perform all points at the beginning of the certification but need to evidence improvement from year to year. Because one principle is based on cattle production it just has to be checked, if the study side farms fulfil the other four principles (Network, 2017).

To reach effective planning and management, the producers have to implement developed systems by a group administration adjusted on the farm to maximize productivity and reduce environmental impact on production. Thus, this principle will be drawn up during the certification cooperation and it has not to be checked as condition for participation.

The natural resource conservation principle focuses on soil protection. In El Cairo there is an efficiently wastewater system with an own sewage plant, so that the producers do not have to use wastewater for the coffee plantations. Further, the remoted producers have established storm water tanks in the forest and none of them used chemical pesticides, so that they all fulfil these criteria. Another part of this principle involves pest and waste management as well as an energy efficiency plan but will also become developed during the cooperation with group administrators.

A further principle revolves around the living quality and includes fair working conditions. It was difficult for me to prove this term, but there is no forced labor or child labor evidence and not just the producer but also the workers organize themselves within *Serraniagua* to have a stronger voice. The paid vacation condition is not fulfilled, but is not applicable to smallholders, which are (according to the SAN) producers using family or household labor or recruit worker within the community. Referred to this definition all study site producer can be ranked as smallholders. Moreover, the workers on every plantation get food and clean water and also breaks during the working time as it is recommended from the SAN contract.

The biodiversity principle is the most important one for the canopy management. It prescribes farms with shade tolerated crops a minimum of 15% total native coverage if they do not fulfil the 40% canopy rule of the *Rainforest Alliance*. The study side producer with canopy lower than 40% or less than 12 native tree species per hectare were checked for this condition. Although they used also non-native shadow trees like *Plantain*, *Nogal* and *Higuerilla* all could satisfy the requirement through including native trees, especially *Guamo* and *Encenillo* for at least 15% of the total coverage. Further conditions under this principle are the prohibition of hunting endangered animals and for the degradation of protected area. Both are also principles of the corporation *Serraniagua*, which cares for the preservation of nature reserves.

4.3 Data acquisition

The object of investigation are 18 different coffee plantations in El Cairo, Colombia. They all have distinguish canopy levels from low shadow up to rustic cultivation, but experience similar geographical conditions like climate, that could have further influence on the production. The coffee plantations were chosen out of the participating producer of *Serraniagua* from coffee experts working there, based on the principle of obtaining the possible highest canopy diversity. Thereby it was feasible to get further information about the plantations, which would be difficult for non-organized farms. For all plantations the data for the production outcome, the size and the sea level were collected by *Serraniagua*.

The outcome is indicated in cargas of raw coffee beans per year and per hectare, where one carga means a 125 kg bag. Therefore, the average outcome of the last five years was used.

For the canopy data of each study plot, I executed the measurements on my own with the help of an employee from *Serraniagua*. We used the approaches of Adeyemi and Adesoye (2016) and Pinilla et al. (2005, p.55) to calculate the percent canopy cover. Hence for every plantation two areas of 20m times 15m were defined in different parts. Most of the coffee plantation had one smaller part with plane trees as shadow and a bigger one with other shadow trees, like *Inga* and *Nogal*. In this case, one area was established in the part with the plane trees and the other one in the part with the mixed trees. For the calculation, I took into account the proportions of both parts to gain representativeness. Also, if there were different parts regarded to the canopy, I considered this fact and if necessary involved additional areas for one study plot in the measurements. I recorded also the local name of each canopy tree and their height.

In each area, the crown projection area (CPA) for every shadow tree was determined. For this the two largest distances of the crown D_1 and D_2 (in meters) were determined and inserted in the following formula:

$$CPA = \frac{\pi \cdot D_1 \cdot D_2}{4} \tag{4.1}$$

The result is the CPA in m^2 and is used for the percent canopy cover C:

$$C = 100 \sum_{i=1}^{n} CPA \; A^{-1} \tag{4.2}$$

where A is the respective area (300 m^2) and the sum includes the CPAs of all shadow trees of this area. The outcome describes the canopy in percentage.

Furthermore, the canopy level was measured with the help of a *forest densiometer*, which includes a mirror with squares for counting its field, which are covered through shadow trees. With this method, the canopy level in percentage was determined in 16 determined points per area for calculating the overall canopy level of the area. The results of both methods were combined to generate the average canopy level for each plot.

All study plots were classified in the five agroforestry systems in order to compare the different influences on outcome between them. Therefore, the criteria of Moguel and Toledo (1999) were used to rank the plots through data of the canopy level, the shadow structure (biodiversity of trees) and the average tree heigh.

4.4 Data description

I used the measured and collected data to create the variables Canopy, Outcome, Sea level and Size. The Canopy describes the shadow level in percentage and the Outcome signifies the amount of grown raw coffee beans per hectare and year, stated in 125 kg cargas. The sea level is expressed in meters for the altitude above sea level and the size characterizes the coffee grown area of the respective study plot in hectare, excluding otherwise used parts.

Most study plots are *Commercial Polyculture* systems with moderate canopy levels between about 30% and 60%. There are just two *Shaded Monocultures*, three *Traditional Polycultures* and one *Rustic system*. The productions under *Shaded Monoculture* and also two of the *Commercial Polyculture* systems have a low canopy level (smaller than 40%), that would not alone require the certification requirements, but for their high native tree proportion they could sell their coffee under the *Rainforest Alliance* label.

For all variables a histogram and a q-q plot were created for a graphical impression and to investigate whether the data are normal distributed (figures 4.1 and 4.2). The histograms further picture the range of the values. In case of the Canopy there is a relatively big span between 23.9% and 81.83%. Also, the Outcome is widely divergent from 1 carga to 11 cargas and the Size ranks from 1.5 ha to 20 ha with an average of 5.07 ha. All 18 study sizes are situated at an altitude between 1359m and 1950m (Sea level).

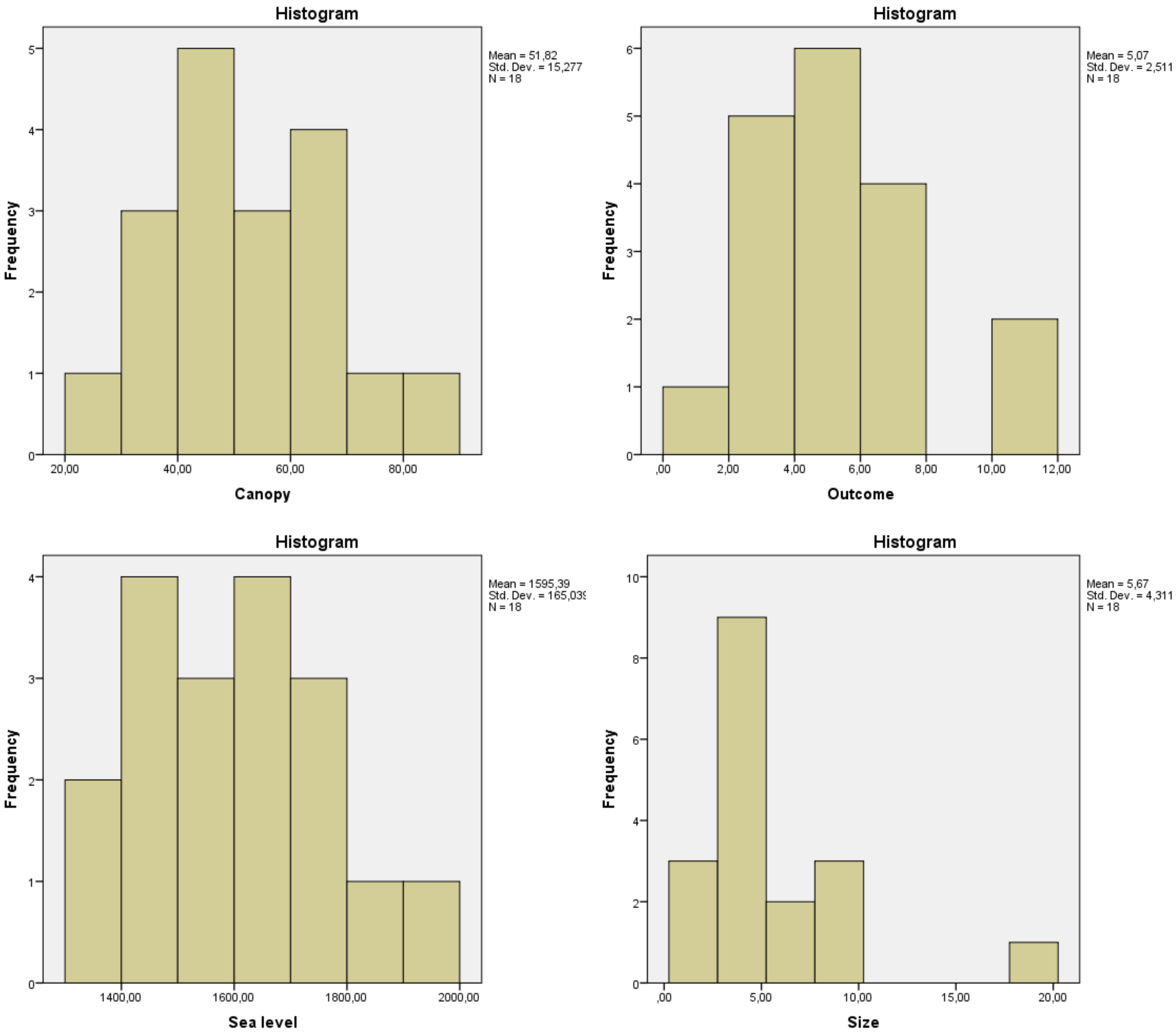

Figure 4.1: Histogram

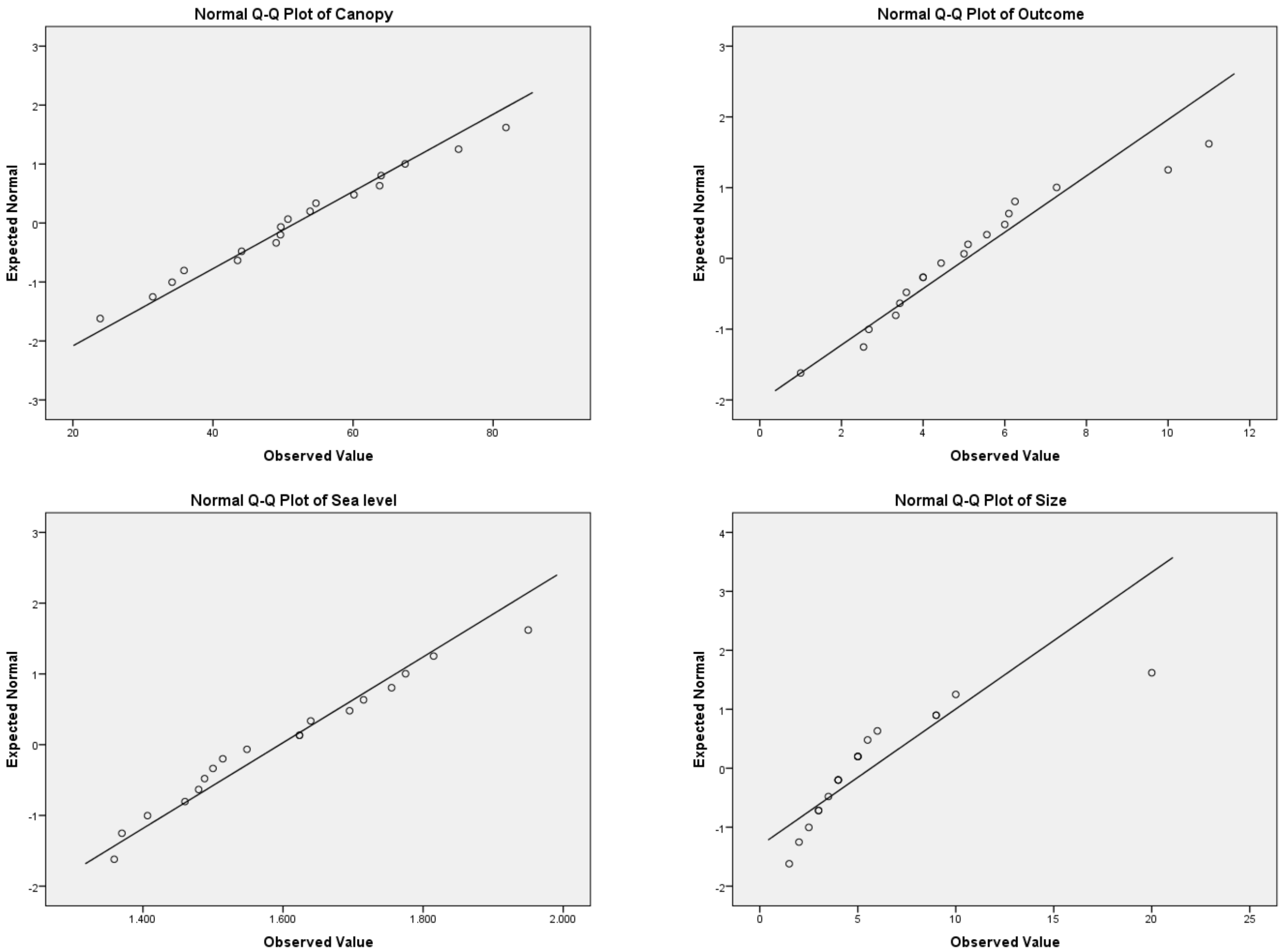

Figure 4.2: Q-Q Plot

Canopy seems to be the nearest variable to the normal distribution with two peaks. In similar way are Outcome and Sea level close to normal distribution, but Outcome might have some outliers for high values and Sea level tends to right-skewness with two peaks. Regarded to the Size, there are high deviations from the normal distribution at first glance, having one peak and outliers varying very widely.

To get a more precise determination for examining the distribution I run the Kolomogorov-Smirnov and the Shapito-Wilk test (Table 4.1).

Table 4.1: Test of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Canopy	.094	18	.200*	.094	18	.200*
Outcome	.153	18	.200*	.094	18	.200*
Sea level	.133	18	.200*	.094	18	.200*
Size	.247	18	.005	.094	18	.200*

* This is a lower bound of the true significance

a Lilliefors Significance Correction

The Kolomogorov-Smirnov test works well for a low number of random samples and verifies the null hypothesis for having normal distributed data. If p is smaller than the significance level at 0.05, the hypothesis can be rejected. Although this is not the case for one of the variables, the Size is exactly on the threshold. The Shapito-Wilk test checks for the same null hypothesis and is chosen because of its high statistical power also for only few samples. For this test, the results clearly confirm a normal distribution for Canopy, Outcome and Sea level, but not for Size. Due to the graphical assessment and the narrow p-values for the Kolomogorov-Smirnov test, these results seem to be the most likely.

4.5 Statistical approach

The data were analyzed with the statistic program SPSS, to determine the relationship between the outcome and the canopy level involving the Size and Sea level as control variables. First of all, a pairwise correlation between the variables was carried out through the Pearson Correlation test.

The results (table 4.2) show a negative moderate correlation between Canopy and Outcome, Sea level and Outcome and also between Sea level and Size.

Table 4.2: Correlations

		Canopy	Outcome	Sea level	Size
Canopy	Pearson Correlation	1	-.278	-.016	.116
	Sig. (2-tailed)		.265	.950	.646
	N	18	18	18	18
Outcome	Pearson Correlation	-.278	1	-.396	-.095
	Sig. (2-tailed)	.265		.103	.706
	N	18	18	18	18
Sea level	Pearson Correlation	-.016	-.396	1	-.269
	Sig. (2-tailed)	.950	.103		.280
	N	18	18	18	18
Size	Pearson Correlation	.116	-.095	-.269	1
	Sig. (2-tailed)	.950	.103		.280
	N	18	18	18	18

Between the other variables there is a weak correlation, but all in all none of the tested correlation is significant. So there is no substantial influence between the variables, which is an important condition for the further analysis.

To investigate the influence from Canopy on Outcome, a regression analysis was implemented, whereas the other variables Sea level and Size were integrated as control variables. For the linear regression, the following model was chosen:

$$\begin{aligned} Y &= f(Can, Lev, Size) \\ \text{with Y} &= a * Can + b * Lev + c * Size \\ \text{whereas Y} &= \text{Outcome}, \text{Can} = \text{Canopy} \\ \text{Lev} &= \text{Sea level}, \text{Size} = \text{Plantation size} \end{aligned} \tag{4.3}$$

But the F-test proves, that this model is not statistically significant and also none of the coefficients a, b and c. The curve fit model and the scatterplot suggest a cubic shape of the regression function referring to the relationship between Canopy and Outcome. Therefore, the model was extended through firstly just inserting Can^2 and then in the next step also Can^3.

For integrating Can^2, the following quadratic regression model results:

$$\begin{aligned} Y &= f(Can, Can^2, Lev, Size) \\ \text{with } Y_i &= \beta_0 Can_i + \beta_1 Can_i^2 + \gamma Lev_i + \delta Size_i + \varepsilon_i \\ &\text{where i is the i-th observation} \end{aligned} \tag{4.4}$$

For adding Can^3 as well, the cubic regression model looks as follows:

$$\begin{aligned} Y &= f(Can, Can^2, Can^3, Lev, Size) \\ \text{with } Y_i &= \beta_0 Can_i + \beta_1 Can_i^2 + \beta_2 Can_i^3 + \gamma Lev_i + \delta Size_i + \varepsilon_i \\ &\text{where i is the i-th observation} \end{aligned} \tag{4.5}$$

5 Results

5.1 Statistical results

Both the linear and the quadratic regression cannot confirm sifnificance. But the results for the adjusted R value show an improvement. For the linear regression function it amounts 0.113 and increases to 0.141 for the quadratic function with Can^2. This means, that for the enlarged model 14.1% of the variance of Outcome can be explained through the independent variables of the quadratic model.

Finally, for the cubic model with including Can^3, the adjusted R value of 0.662 describes a moderate degree of correlation. Table 5.1 pictures the results of the regression analysis for the cubic model. In contrast to the other models, this one results in a significant influence on the Outcome.

Table 5.1: Anova[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	81.609	5	16.322	7.655	.002[b]
Residual	25.585	12	2.132		
Total	107.194	17			

a Dependent variable: Outcome

b Predictors: (Constant), Canopy, Canopy2, Canopy3, Sea level, Size

Sig. means significance

Table 5.2 displays the results for the effects of the particular coefficients of the cubic function on the Outcome. It shows, that just the Canopy coefficients (Canopy, Canopy2 and Canopy3) are significant. Hence there is no statistically significant dependence from Outcome on the control variables Sea level and the Size.

The constant describes the interception with the Y-axis (Outcome) and is also not significant, which is not disturbing for the model. It just means, that the average value of Outcome is not significantly differing from the zero point, if the independent variables are zero, as well.

Table 5.2: Coefficients[a]

	Unstandardized Coeff. B	Unstandardized Coeff. Std. Error	Standardized Coeff. Beta	t	Sig.
(Constant)	-44.970	13.498		-3.332	.006
Canopy	3.537	.736	21.517	4.802	.000
Sea level	-.003	-.002	-.169	-1.072	.305
Size	-.168	.087	-.288	-1.933	.077
Canopy2	-.069	.015	-44.877	-4.738	.000
Canopy3	.000	.000	23.619	4.584	.001

a Dependent variable: Outcome

Coeff. means coefficients

Std. Error means standard error

For the cubic model the following equation applies:

$$\begin{aligned} Y &= f(Can, Can^2, Can^3, Lev, Size) \\ \text{Outcome} &= -44.970 * Can - 0.069 * Can^2 \\ &+0.00 * Can^3 - 0.003 * Lev - 0.168 * Size \end{aligned} \tag{5.1}$$

The resulting regression curve displays a positive influence on the predicted outcome for increasing canopy up the maximum point of 43.51% canopy and 11 cargas per year and ha. After this point, the predicted outcome decreases for increasing shadow levels up to about 60%, when it will rise again slightly. The peak curve is very steep, which means that producer, which are close to the maximum point obtain high outcomes, but for small deviations in canopy levels can quickly make losses. Hence the outcomes close to the peak are very sensitive for changes in canopy. This cubic shaped relationship can be sensed in the scatterplot for Canopy and Outcome (figure 5.1).

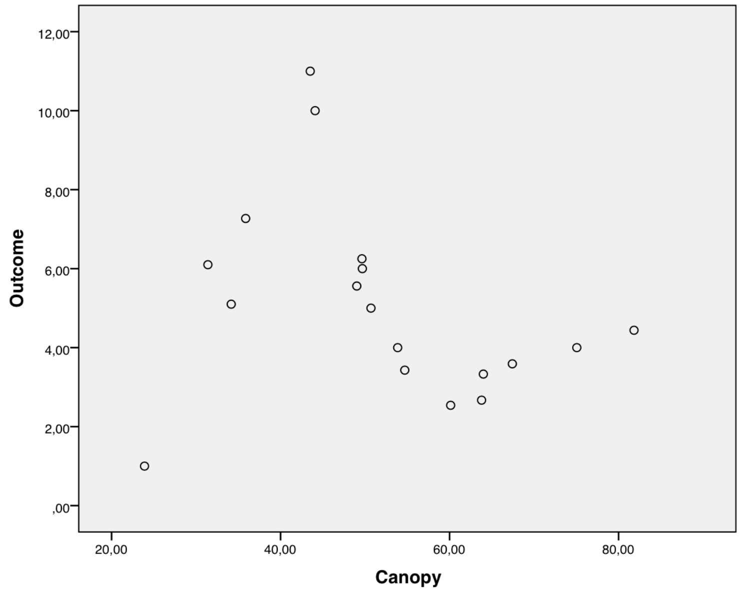

Figure 5.1: Scatterplot for Canopy and Outcome. Outcome is in cargas (125kg) per ha and year. Canopy is in percentage.

The graphic attests, that study plots with very low Canopy also have a low outcome, which increases consequently for higher shadow levels. There is one clear peak, whereby values of high Canopy correlate with low Outcome results.

5.2 Application on the premium

The certification premium for canopied coffee should be a compensation for the coffee producer for their additional environmental service in comparison to the sun grown coffee and the resulting costs. Further it should constitute an incentive for the producer to implement an ecological supporting growing system. With the assumption, that shadow trees promote environmental aspects, the premium should at least include the additional costs for a higher canopy level (if there are actual more costs).

Like the results of the study plots in El Cairo showed, there is an income growth through increasing canopy up to the level of 43.52%. For the cases of all lower levels the economical objective should be sufficient incentive for expanding the canopy. If the certification organizations want to motivate the producers to raise their shadow for higher values than the economic optimum, they should pay them the resulting expected income losses as premium difference. This means, that producers with a canopy level, higher than the outcome maximizing point, should get a markup on the already existing premium for their expected losses. This requires, that higher canopy levels indeed improve ecological aspects, otherwise the mark up would be inefficient (therefore, section six provides information about the influence from canopy on the biodiversity).

The outcome data reveal the respective amount of cargas per hectare for each farm, whereby 11 (per year and hectare) is the maximum amount, the producer could reach for adapting the canopy level to the economic optimal point. To gain the yield out of the outcome data, the selling price and the producing costs have to be included. They are needed to calculate the profit per carga coffee beans.

The profit results from the current price information of the FNC (converted in USD with the current exchange rate) from February 2018 with subtraction of the costs. Currently, the producers can sell one carga of raw coffee for 240.67 USD. In Colombia, usually the workers are paid per picked amount of coffee beans. There is a unified wage of 36.25 USD per carga in El Cairo. Because the wages account for 50% of the costs (cleaning, drying, transport and material), total costs amount 72.5 USD per carga (information from the Federación Nacional de Cafeteros). The coffee is sold as dry parchment coffee, hence there are no costs for the roasting process.

Therefore, the profit per carga is:

$$240.67 \text{ USD/carga} - 72.5 \text{ USD/carga} = 154.19 \text{ USD/carga} \tag{5.2}$$

Thus, the recommended price premium differences per kg (1 carga = 125 kg), based on the yield loss for increasing canopy cover, can be calculated as follows:

$$\text{Premium difference} = \frac{(11\text{carga/ha} - \text{carga/ha}) * 154.19 \text{ USD/carga}}{\text{carga/ha} * 125\text{kg/carga}} \tag{5.3}$$

whereby the difference between the maximum possible outcome of 11 cargas per hectare and the reached outcome of the respective farm is multiplied with the profit per carga (from 5.2). In order to obtain the result in kg it is divided accordingly. The therefore calculated premium difference is the recommended mark up on the existing premium, that producers should receive as a compensation for their expected losses.

For inserting the different outcomes of the study plots in the equation, the result is a premium difference from 1.48 USD for around 50% cover, 2.16 USD for 75.06% and 1.82 for the highest measured canopy level of 81.83%.

Due to the fact, that the outcome slightly increases for canopy over 60%, the lower premium differences for over 80% in comparison with over 70% seems logically.

There is no information available about actual premium differences for various canopy level to compare the results, because many certification organizations just have one determined premium for all producer fulfilling their requirements.

But through considering the realized premiums for certified coffee in section 3.1, which are widely diversified between 0.33 and 1.37 USD per kg, the high amount of the premium differences becomes obvious, regarded that it is thought as a mark up on the normal premium for canopied coffee.

6 Biodiversity

There are a lot of different studies about the influence of canopied management systems on biodiversity (Sanchez-Clavijo et al., 2009; Greenberg et al., 1997; Perfecto and Armbrecht, 2003; Perfecto et al., 2005). Researchers use the criteria of the five growing systems after Moguel and Toledo (1999, pp.12–14) and Philpott et al. (2008) (section 2.1.1) to make the relationship comparable through the canopy structure (Mas and Dietsch, 2003, 2004; Philpott et al., 2008). However, there is no optimal canopy level or management system as one solution to maximize the biodiversity of birds, ants and other concerned animals in general, but rather it is depending on the organism (Perfecto and Armbrecht, 2003). Since Colombia has the highest bird species richness in the world with the Andes as important ecosystem for birds (Sanchez-Clavijo et al., 2009), the focus lies on the influence from canopied coffee systems on the biodiversity of birds.

There is a study about biodiversity influence including the surrounding of El Cairo (Sanchez-Clavijo et al., 2009), but it just analyses the effect of canopied coffee as one growing method on the biodiversity of birds without considering the differences between the separate canopied management systems.

Several studies have shown, that not solely the canopy cover is crucially for the biodiversity of birds, but rather it is the agroforestry system, which is also determined through the tree species richness and the tree height as important factors for the birds (Philpott et al., 2008; Perfecto and Armbrecht, 2003; Mas and Dietsch, 2003).

The research of Philpott et al. (2008) confirm a correlation between the different agroforestry systems *Shaded Monoculture* (SM), *Commercial Polyculture* (CP), *Traditional Polyculture* (TP) and *Rustic* (RU) and the changes of bird species richness. The authors collected data from different investigations in South America about different canopied coffee systems and the related biodiversity measurements.

The biodiversity was determined through a comparison with a close forest. They found a negative relationship between the management intensity and the species richness, whereby between the agroforestry systems, the SM has the highest management intensity and the RU the lowest one. Although they found no significant species change for the SM compared to the forest, they reasoned this discrepancy with chosen SM plots, which were similar to some CP plots and had mainly bird-attractive trees. Hence, they came to the conclusion, that especially RU should be supported by organizations and both sun grown coffee and SM pushed for restoring.

For certification organizations with biodiversity protection goals these results assign the SM coffee the lowest ecological value and the RU the highest value. Hence, they should give an incentive to the producer to change the system through including potential yield losses in the premium. Consequently, the optimal premium for canopied coffee should differ between the agroforestry systems.

Table 6.1: Yield losses of Agroforestry systems

Agroforestry system	Canopy	Yield loss
Shaded Monoculture	**31.40**	**.99**
	23.90	12.34
Commercial Polyculture	**42.51**	**.00**
	44.09	0.12
	35.87	0.63
	49.63	0.94
	49.68	1.03
	49.02	1.21
	34.16	1.43
	50.70	1.48
	53.86	2.16
	54.70	2.72
	60.13	4.11
	75.06	2.16
Traditional Polyculture	**67.43**	**2.55**
	64.00	2.84
	63.79	3.85
Rustic System	**81.83**	**1.82**

The deviation of the 18 study plots of El Cairo into the agroforestry systems was used to consider their biodiversity supporting aspects. Table 6.1 pictures for each plot the corresponding agroforestry system, the canopy cover and the outcome loss, which means the loss in yields compared to the maximum outcome (calculated with the formula 5.3).

The entries within the system categories are ranked after outcome losses, beginning with the lowest value. For all categories, the bolded values are the canopy levels with the lowest loss in yields, but maintain at the same time the biodiversity of birds for the respective system. As already mentioned in section 5.1, producer of the SM (which have the lowest canopy cover) should have an economical driven incentive for changing the system into the CP.

Many of the study plots within the CP could reach higher yields and maintaining the agroforestry system. From the organizations perspective the RU system would be optimal considering the species richness and even implies a lower premium difference in comparison with the TP. But since there is only one RU system within the study plots and just a few plantations with very high canopy levels, the lower yield losses could also be reasoned for other causes. However, the additional premium for the producer should at least amounts 1.82 USD per kg to compensate for expected yield losses, if they would otherwise choose the economic optimum.

7 Conclusion

The stated hypothesis, that increasing canopy within certified coffee leads to lower outcomes, cannot be confirmed. But it is also not on the contrary; instead there is a cubic shaped function, which describes the effect on the outcome for various shadow, for including all certified farms.

Further, it has to be differentiated between the two options for fulfilling the requirements of the *Rainforest Alliance* (a minimum level of 40% canopy without considering the type of trees or 15% with native trees).

In the case of just focusing on the first possible condition - assuming that all producer with lower canopy would be excluded - the analyzed output maximizing level of 43.52% would support the hypothesis, as after this point the output decreases. Thus, for producers without native trees it is optimal to stay close to the minimum requirement.

For the second possible minimum level (including all producer), the hypothesis has to be rejected and the cubic function can be considered for the relationship between canopy and outcome. Therefore, the maximum outcome is reached through a canopy cover of 43.51%. As a consequence, producer with lower shadow should raise the level for increase their output, even if they already fulfill the certification conditions. The lowest measured canopy level even resulted in the smallest outcome and then increased the amount through getting higher up to the point of 43.51% and after reaching the maximum, the influence becomes negative until 60.13%, where the function again rises slightly. So, producers over the maximum point need a compensation for the respective losses in outcome. The control variables size and sea level don't show statistical significance.

Compared with the results of other researches, the maximizing canopy level of 43.51% is corresponding. Perfecto et al. (2000) found out similar results. They also could not prove a significant effect from the altitude (sea level) on the yield but got a negative significant effect for the correlation between canopy level and yield. The optimal yield was reached between 38%-48% canopy level and decreased for over 50%. The relationship between canopy and yield was therefore in form of a hump-shaped regression function. Other papers identified canopy levels between 40%-50% (Alemu, 2015) and 35%-56% (Baggio et al., 1997) generating the highest outcome, but they included sun-grown coffee on their studies. The balance between an acceptable photosynthesis level and simultaneous an optimal temperature might be reason for the best results in the medium range of canopy cover (Shalene et al., 2014). Solely the small increase of outcome for canopy levels over 60% is deviating from other results and is not suited with the biological explanation for the relationship. A possible reason could result from the types of shadow trees. While the study plots with high shadow levels almost use native trees like *Inga* without fruits for the whole canopy, the plantations between 50% and 60% canopy include a lot of fruit trees. This leads to a competition between the fruits and the coffee beans for nutrients and can therefore lead to biennial bearing and a decreasing bean size. Hence, fruit trees have a more restrictive influence of coffee yield, than other shadow trees do (Vaast et al., 2005).

In order to estimate the environmental service of canopied coffee, the biodiversity impacts should be considered. External data from other researches in South America confirmed a higher biodiversity of birds for agroforestry systems with more shadow (Philpott et al., 2008). But, higher canopy levels alone do not necessarily lead to an increase in biodiversity, because there are additional influencing aspects like the tree height. So, it is recommended to divide the farms into the agroforestry system, to compare their influence on the biodiversity.

Further, organization should consider the expected losses in yields for the deviation of the economical optimum shadow, if they want to support the ecological protection of the different agroforestry systems. Therefore, biodiversity aspects were linked with the systems and the respective yield losses of the study plots in El Cairo. The results reveal a need of high premium differences for the most biodiversity friendly system (regarded to bird species) to compensate the losses. Consequently, to maintain these systems, the organizations should pay the respective producers an additional mark up (yield losses) on the premium.

Although the case study reveals meaningful results, there are some limits, grounded on the measuring effort and the complexity of the ecosystem. To get more explicit results of the regression analysis, it would be necessary to involve a higher number of plots with various shadow, especially for examining the influence for very high canopy levels. Due to the possible impact of geographical factors on the influence from canopy cover on the outcome, there might be divergent results for different locations, which makes it complicated to generalize findings in this field (Shalene et al., 2014).

It further has to be mentioned, that there are others environmental influences from canopy, besides the biodiversity, although this is considered as very important. Further studies could focus on the effects of other ecological aspects, like the soil.

Also, the influences from different canopy level on the quality might be interesting, because this could lead to price differences. If the producer would sell the coffee on the international market, they could benefit from better quality through higher income, whereas in El Cairo the quality of the canopied plantations had no influence on the price. There is an assumption of positive effects from higher canopy levels on the quality, but with restriction referring to the altitude (Shalene et al., 2014). Bosselmann et al. (2008) discovered a negative influence from shade on some sensory quality attributes just for high altitudes which could be resulting from the reduced temperature and radiation but could not find a significant influence on lower altitudes.

Another possible yield increasing aspect can be the fruits and the wood of the shadow trees as further income source. This opportunity was not taken into account, because most of the coffee producer did not sell the earnings of the shadow trees but used them for own consumption. Just the plantains were sold in the villages, but according to the statements of the producer, this income source just represents a very small share.

Generally, the work is a possible approach for further studies and was implemented in response to the problematic of the current certification system for special coffee, where one uniform premium for all canopy levels can lead to inefficient growing management.

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