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Management of intrinsic quality characteristics for high-value specialty coffees of heterogeneous hillside landscapes

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Peter Roman Django Läderach
aus
Bern, Schweiz

Hauptberichterstatter:	Prof. Dr. Jürgen Pohlan
Berichterstatter:	Prof. Dr. Heiner Goldbach
Vorsitzender:	Prof. Dr. Dieter Wittmann
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Management of intrinsic quality characteristics for high-value specialty coffees of heterogeneous hillside landscapes

Tropical hillsides are ecologically and socially diverse with a multitude of small- to medium-sized farms that offer a potential treasure chest of high-value market crops. Specialty coffees, for example, earn a substantial price premium and are therefore a promising opportunity for farmers. Coffee quality is determined by the natural environment and farm management practices. To sell high-priced coffee, farmers must produce beans desired by consumers who are willing to pay more for specific quality profiles. A targeting of the production practices to suit the continuously-changing market demands is necessary; the focus must be on controlling the processes that determine the quality characteristics.

The present research aimed to develop a framework to manage the intrinsic coffee quality of heterogeneous hillside landscapes. In a two-tiered approach, firstly spatial prediction models were developed and tested to identify the comparative advantage of environmental niches and secondly systematic farm management practices were developed and tested to turn the comparative advantage of farmers into a competitive advantage. Commercial sensorial data of the two Colombian departments of Cauca and Antioquia, of the Veracruz department in Mexico and of the five coffee growing regions in Honduras were used to develop and test the framework.

The results suggest that the framework is highly viable; the information generated is highly novel, is high-medium actionable and is medium deliverable to stakeholders. The specific conclusions derived are: (1) The production environment of coffee (natural environment, agronomic management and post-harvest processes) is variable over space. (2) Beverage quality of coffee is dependent on the production environment. The combination of decisive quality factors varies from location to location, and so does the contribution of each factor. (3) Production factors can be identified and their impact quantified. Subsequently the factors can be systematically controlled and managed to improve product quality. (4) Site-specific systematic and cyclic quality control processes are required to decrease produce variability and deliver a product sought by the market. (5) The approach is twofold, firstly the identification of suitable environmental niches followed by definition of site-specific management. (6) Farm management interventions are not always statistically significant but often relevant for farmers. (7) Qualitative quality-control methods using commercial data are viable indicators for quality measurements so long as consistent, skilled evaluators (cuppers) are selected in preliminary testing.

Manejo de las características de calidad intrínseca para cafés especiales de alto valor en terrenos heterogéneos de ladera

Las laderas tropicales son terrenos ecológicamente y socialmente diversos los cuales cuentan con una gran variedad de pequeñas y medianas fincas que constituyen un verdadero tesoro para los cultivos comerciales de alto valor. Los cultivos de cafés especiales por ejemplo, ganan un valor agregado y son, por lo tanto una oportunidad prometedora para los agricultores. La calidad del café está determinada por el medio ambiente y las practicas agrícolas. Para vender café a un precio alto, los productores deben producir cafés requeridos por los consumidores, quienes a su vez están dispuestos a pagar más por ciertos perfiles de calidad específica. Es necesario hacer una intervención en las prácticas de producción acordes con las exigencias de un mercado constantemente cambiante. El enfoque se debe basar en el control de los procesos que determinan las características de calidad.

Esta investigación esta encaminada a desarrollar un marco teórico para controlar y manejar la calidad intrínseca del café de laderas heterogéneas. Se desarrollaron y probaron primero, los modelos de predicción espacial para identificar la ventaja comparativa y los nichos ambientales y seguidamente se desarrollaron y probaron las prácticas sistemáticas del manejo agrícola específico para convertir la ventaja comparativa de los productores en una ventaja competitiva. Se usaron datos sensoriales comerciales de los departamentos de Cauca y Antioquia en Colombia, del departamento de Veracruz en México y de cinco regiones de café en Honduras para desarrollar y probar el marco teórico.

Los resultados comprueban que el marco teórico es totalmente viable, la información generada es altamente novedosa, es realizable y es entregable a los participantes. Las conclusiones específicas derivadas son: (1) El ambiente de producción (ambiente natural, procesos de manejo agrónomo y post-cosecha) es variable y depende del sitio. (2) La calidad de la bebida de café depende del ambiente de la producción. La combinación de factores decisivos para la calidad varia de un lugar a otro y así mismo es para la contribución de cada factor. (3) Los factores de producción pueden ser identificados y su impacto cuantificado. Subsecuentemente, los factores pueden ser sistemáticamente controlados y manejados para mejorar la calidad del producto. (4) Se requieren procesos específicos-sistemáticos y cíclicos de control de calidad para disminuir la variabilidad del producto y producir un producto requerido por el mercado. El enfoque es doble, primeramente la identificación de un nicho ambientalmente apto seguido de la identificación del manejo específico por sitio. (5) Las intervenciones en el manejo agronómico no siempre son estadísticamente significativas pero a menudo son relevantes para los productores. (7) Métodos cualitativos de control de calidad usando datos comerciales son indicadores viables para medir la calidad siempre y cuando catadores consistentes y calificados sean seleccionados en la prueba preliminar.

Management der intrinsischen Qualitätscharakteristiken von hochwertigen Spezialitätenkaffees aus heterogenen Hanglagen

Der Kaffeeanbau in tropischen Hanglagen variiert ökologisch sehr stark und ist sozial besonders geprägt durch eine Vielzahl von kleinen und mittleren landwirtschaftlichen Betrieben, welche ein hohes Potential für die Produktion von hochwertigen Agrarprodukten haben. Spezialitätenkaffees werden mit einem Mehrwert belohnt und sind deshalb eine vielversprechende Option für diese Bauern. Kaffeequalität ist wesentlich durch die natürlichen Umweltbedingungen und die agronomischen Praktiken bestimmt. Um hochwertige Kaffees vermarkten zu können, müssen die Bauern einen Rohkaffee produzieren, welcher vom Markt nachgefragt wird und für welchen der Konsument bereit ist, einen entsprechenden Aufpreis zuzahlen. Deshalb ist eine kontrollierte gezielte Produktion notwendig um mit den sich konstant ändernden Marktpräferenzen Schritt halten zu können.

Die vorliegende Arbeit hat zum Ziel ein Rahmenwerk vorzulegen, welches es erlaubt, die Kaffeequalität aus heterogenen Hanglagen einschätzen, kontrollieren und beeinflussen zu können. Im ersten Teil der Dissertation werden räumliche Vorhersagemodelle entwickelt und getestet, um den komparativen Vorteil von Umweltnischen zu bestimmen. Im zweiten Teil erfolgt die Analyse der systematischen Anbaupraktiken, um den komparativen Standortvorteil der Bauern auch kompetitiv nutzen zu können. Kommerzielle sensorische Daten von Kaffees aus den kolumbianischen Departamentos (entspricht Bundesländern in Deutschland) Cauca und Antioquia, aus dem Departamento Veracruz in Mexiko, und aus den fünf Kaffeebauzonen in Honduras wurden verwendet, um das Rahmenwerk zu entwickeln und zu testen.

Die Ergebnisse zeigen, dass das Rahmenwerk höchst brauchbar und die mit dem Rahmenwerk generierte Information höchst neuartig, hoch bis mittelmässig umsetzbar, und mittelmässig zugänglich ist. Insgesamt lassen sich folgende Schlussfolgerungen ziehen: (1) Das Produktionsumfeld (natürliche Umwelt, agronomisches Umfeld und Nachernteverfahren) ist standortsvariable. (2) Die Tassenqualität hängt vom Produktionsumfeld ab. Die Kombination der qualitätsbeeinflussenden Faktoren variiert von Standort zu Standort und ebenfalls der Beitrag der einzelnen Faktoren. (3) Limitierende Produktionsfaktoren konnten identifiziert und deren Einfluss quantifiziert werden. Dies erlaubt eine systematische Kontrolle und Beeinflussung einzelner Faktoren, um die Produktqualität verbessern zu können. (4) Ortsspezifische, systematische und zyklische Qualitätskontrollprozesse sind notwendig, um die Variabilität der Produktqualität zu verringern und ein vom Markt nachgefragtes Produkt herzustellen zu können. (5) Die Herangehensweise beinhaltet zwei Teilschritte. Zuerst werden geeignete Nischen identifiziert und darauf basierend das ortspezifische Qualitätsmanagement definiert. (6) Managementinterventionen sind nicht immer statistisch signifikant, aber trotzdem oft relevant für den Bauern. (7) Qualitative Methoden zur Qualitätskontrolle, basierend auf kommerziellen Daten, sind brauchbare Indikatoren für die Erfassung der Tassenqualität, so lange gut ausgebildete Verkoster in Voruntersuchungen ausgewählt wurden.

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1 INTRODUCTION

Since the early 1980s the dominant feature of the international commodity markets has been a sharp downward trend in price (Maizels, 1994). Developing economies are destabilized by fluctuations in primary commodity prices due to their strong reliance on foreign exchange earnings on commodities (Dick et al., 1983). Despite efforts to stabilize prices, commodity prices continue to decline over time (Grilli and Yang, 1988). Although price booms do occur, they tend to be shorter than the slumps, which also tend to be worse than the price recoveries (Cashin et al., 2002). The slump of coffee prices led to a 20-year low in 2001; taking inflation into account, the 'real' price is now at a mere of 25% of its level in 1960 (Cashin et al., 2002; Gresser and Tickell, 2002). The 25 million coffee producers worldwide, 70% of whom are smallholder farmer working on fewer than 5 ha (Gresser and Tickell, 2002) have been among the hardest hit by the decline of commodity prices. Coffee is grown in 70 countries on East African, South Asian and Latin American hillsides where millions of people are employed in producing, processing, trading, roasting and retailing. The entire agricultural system has become jeopardized as farmers strive to cut costs, producing coffee becomes unaffordable and farmers stop maintaining their land and coffee trees.

Tropical hillsides are ecologically and socially diverse with a multitude of small- to medium-sized farms that offer a potential treasure chest of high-value market crops. The diverse conditions of hillside areas provide major opportunities for utilizing different ecological niches required to produce high-value specialty crops. One option for farmers for increasing their incomes is to diversify into higher value coffees. Specialty coffees, in contrast to bulk commodity coffee, earn a substantial price premium and are therefore a promising opportunity for farmers. To sell high-priced coffee, farmers must produce beans desired by consumers who are willing to pay more for specific traits. Rigorous, continuous cyclic quality-management schemes are necessary so that farmers can react on the emerging and fast-changing markets for specialty coffee. Existing approaches for quality management of volume coffee can not cope with the requirements of the supply chains for specialty coffee.

1.1 Problem definition

In the last decades a process of market fragmentation and differentiation into higher-valued products has occurred. Product lines became vertically differentiated offering to the consumer the opportunity of choosing their products based on various objective and subjective quality attributes, such as monetary, physical, visual, social, information, or service attributes. Differentiated products are beneficial for both ends of the supply chain; the consumers receive a product tailored to their requirements and the producer is rewarded for his effort (Borregaard and Dufey, 2005).

Quality is a measure of the extent to which customer requirements and expectations are satisfied (Lochner and Mater, 1990). Consumers' perceptions and attitudes define which aspect of a product is critical to consumer value (Schröder, 2003). Quality relates to the fulfillment of requirements through a set of inherent characteristics, where inherent refers to an existing characteristic as opposed to an assigned attribute (ISO, 2000). This implies that quality is not static, since customer expectations can and do change. Quality therefore involves identifying specifications and standards to meet customer needs and preferences (design quality) and producing products that satisfy those specifications and standards (conformance quality) (Lochner and Mater, 1990).

The specialty coffee sector is only one example of a newly-emerged market niche. Commodity coffee has behaved over the last two decades as a paradigmatic primary commodity, exhibiting sustained declines in its term of trade, punctuated by occasional periods of price rises (Fitter and Kaplinsky, 2001). Specialty coffees, however, in contrast to bulk commodity coffee, earn a substantial price premium and are therefore a promising opportunity for farmers.

Quality coffees are particularly suited to the intensive management that can be provided by small-sized production units. Furthermore, the diverse climatic conditions and soils of hillside areas provide major opportunities for utilizing different ecological niches required to produce specialty coffee.

Coffee quality is determined both by the natural environmental factors such as altitude, aspect, rainfall and soils and by farm management practices such as shade management and harvest practices (fermentation time, drying, storing) The quality is therefore highly variable in both space and time. The question to be addressed then is, how can farmers, in their highly variable environments, produce beans desired by consumers as the demand for high-quality specialty coffees grows and becomes an increasingly important component of the market?

The focus must be on controlling the processes that determine the characteristics of the green beans so that the coffee liquor has the qualities that are sought by customers, rather than on controlling the end product by inspection, as is currently the case. This implies the need for a focus change from inspection to prevention (Lee and Whang, 2005). In this context the understanding of supply-chain quality management becomes increasingly relevant (Robinson and Malhotra, 2005). Quality practices must advance from traditional and product-based mind-sets to an inter-organizational supply-chain orientation involving all actors along the supply chain. The change from generic to continuously-emerging specifics implies a shift from product to process. Processes represent a continuous series of actions or operations directed to an end. For the specialty-coffee sector this means a collaborative effort between supply chain participants in process-based management to interlink high-quality production environments to final consumer niches.

1.2 Demand for change

Recent research has demonstrated that quality does indeed pay. The added value gained by premiums paid for quality is much higher than for premiums paid for a label. This is especially true for specialty coffee, for premium coffees the added value is similar (Figure 1). Importers and roasters are the final judges who decide what price they are willing to pay for coffee of a given quality. The high-quality coffee trade therefore requires a full understanding and appreciation of why a particular coffee attracts the interest of buyers (ICO, 2000) so that producers will be able to produce beans that will satisfy the customers’ demands.

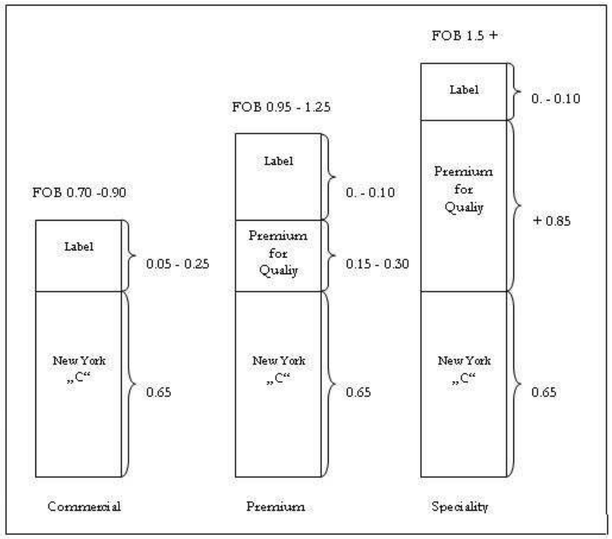


Figure 1: Impacts of quality and certification on green coffee prices.
Adapted from (CIMS, 2004)

Customer satisfaction in the conventional paradigm for bulk coffee is shown in Figure 2. In this model, customer satisfaction is 100% when the product complies with the standard requirements or 0% when it does not. Whilst it is easy to comply with the requirements required for bulk coffee, the benefits are also small. The requirements for bulk coffee do not form a specific target rather a range within which quality has to fall, for example a range in full defects between 9 and 23 is acceptable. Specifications on defect will be presented in the next chapter.

Figure 2: Conventional quality paradigm used for bulk coffee.
Quality specifications for bulk coffee allow a wide range of quaities (Bhote and Bhote, 2000).

In the markets for high-quality coffee, product specifications are even more important. For example, to be classified as specialty grade (Specialty Coffee Association of America SCAA standards), “no primary defects are permitted, and only 5% by weight can be above or below the indicated screen size" (Note the wording, "Indicated screen size", which implies that the customer chooses according to his preferred size). Purchasers of high-quality coffees assume that their product complies with certain specifications but they most importantly demand that their product has a distinct expression of one or more of flavor, body and fragrance. Therefore the new focus in the specialty quality segment of the industry must be on controlling the processes that determine the quality characteristics of the green beans so that the coffee liquor is sought after by the end user. In consequence, actors in the coffee supply-chain must attempt to reduce variability in both the process and the product, and thereby moving the quality characteristics closer to the target values specified by the customer. The pursuit of quality therefore means creating products that reduce economic losses due to variation away from the target. The target is very narrowly defined and only small deviation will cause loses (Figure 3).

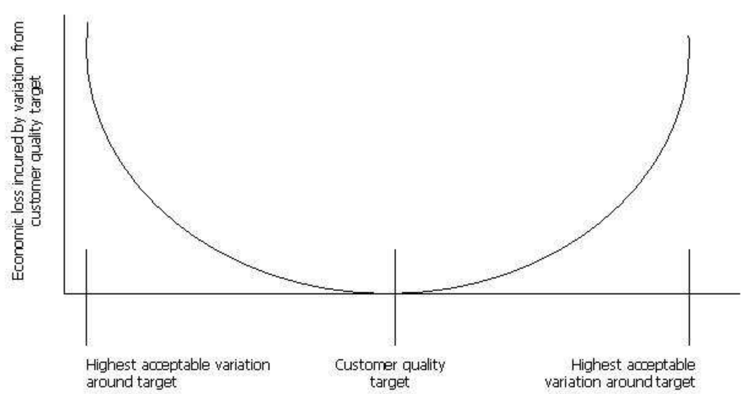


Figure 3: The new quality paradigm used for specialty coffee.
Adapted from (Bhote and Bhote, 2000).

Targeting the customers' demands implies increasing investment in information and control mechanisms to comply with standards and customer trends. According to the market channel continuum (Goldsmith and Bender, 2003) is the lowest level of information need represented by commodity coffee, which only requires some generic physical information about defects in the sample. Further product differentiation by search attributes such as bean size and variety implies a little more sophisticated tracking and control system (Figure 4). Differentiation by experience attributes, such as cupping tests, requires tighter quality evaluation by an expert panel together with a demanding tracking and quality control system. The credence model has the additional requirement of trust in the company marketing the coffee, which is only possible through long-term commitment and high-quality standards. The highest level of product differentiation in the market channel continuum is the exclusivity model, where the consumer has full trust in the coffee retailer with regard to the origin and quality of the coffee, based on personal relationship either in the store, by telephone or over the internet.

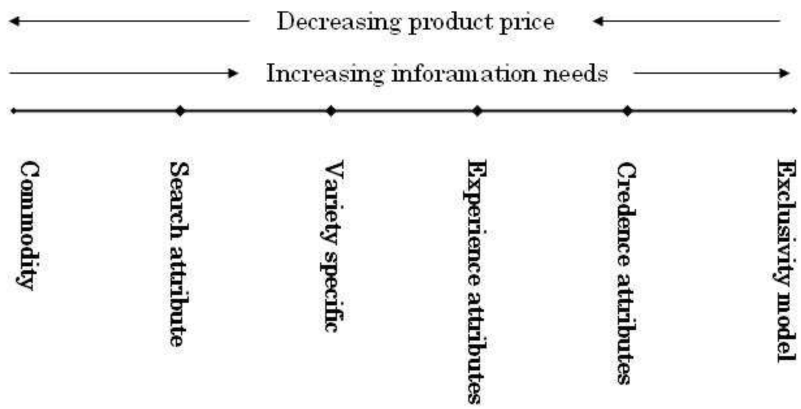


Figure 4: Marketing channel continuum.
Adapted from (Goldsmith and Bender, 2003).

For farmers to move from commodity coffee to specialty coffee requires that they not only increase the quality of their product, but that information about it is available to the end user, so that a system of information management is necessary. Communication and trust between actors in the supply chain will eventually lead to consumers' increased satisfaction with the product. The supply-chain approach and quality management of commodity coffee cannot cope with the newly emerging specialty coffee markets. A new approach to quality management in the supply chain is therefore necessary to move from a focus on the product control for commodity coffee to a focus on process control in specialty coffee.

1.3 Hypothesis, goal and objectives

1.3.1 Central hypotheses

1. That association exists between the organoleptic characteristics of coffee and the natural and production environment in which it is grown.
2. That these associations can be identified through systematic analyses of large numbers of commercial samples.
3. That using novel approaches and modern information technology will provide the bases for differential, site-specific product management that consistently harnesses the potential of both the natural and production environments to produce high-quality specialty coffee.

1.3.2 Overall development goal

To accrue sustainable economic benefits to the coffee-growing community and their partners, while maintaining the environmental resource base, by facilitating producer participation in supply chains for high-value coffee.

1.3.3 Objectives

General objective

To use analyses of product quality and associated growing practices in coffee production systems to derive the concepts and methodology for both site-specific and regional quality management. To devise quality management methodologies for use on farm and in the supply chain that facilitates farmers' participation in the production of specialty coffees leading to increased income and improved livelihoods.

Specific objectives

1. To describe and quantify the impact of the natural environment on coffee liquor quality.
2. To describe and quantify the impact of agronomic management and post-harvest processes on coffee liquor quality.
3. To develop, compare and test spatial analyses tools for the identification of high quality coffee niches.
4. To develop and test concepts for site specific agronomic and post-harvest management practices for improved coffee quality.
5. To determine the utility of qualitative quality control methods.

1.3.4 Problem and objective tree

Figure 5 summarizes the sequences of the problem tree starting out in the trunk of the tree with the decreasing income of coffee farmers up to the branches representing the lack of real world data, environmental data, analyses techniques and data management systems. In the opposite direction the objective tree states the output, general objectives, objectives and sub-objectives to confront the defined problems.

1.4 Approach

The approach differs from those used in traditional agricultural research. First, methodologies were required to characterize the spatial variation in factors that drive product quality. Secondly, organizational structures were required where producers and others contribute knowledge to assess the variation of product quality down to the farm or field level. Thirdly, analytical techniques needed to be adapted to make sense of the information collected. Methodologies to characterize the factor variation included tests of significance, correlation, regression, cluster, principal component and discriminate analyses, spatial visualization (mapping), Bayesian statistics and prediction modeling. The organizational structure involved all partners of the supply chain to allow the use of commercial data.

- Farmers harvested the berries and provided information on farm management and post-harvest activities;
- Associations assisted in developing the sampling design and coordinating the field work;
- Exporters and the roaster assessed the beverage quality and provided insight on cupping procedures and quality preferences; and
- Researchers generated environmental data, compiled and administrated the production data, developed a online data warehouse system, and analyzed the data generated by the chain.

For the field experiments the data were generated under a semi-controlled environment that is the plots where chosen in advance, specific parameters were controlled and treatments applied. In the thesis exploratory analyses are distinguish where commercial data was used from case control studies where data generated in semi-controlled environments were used.

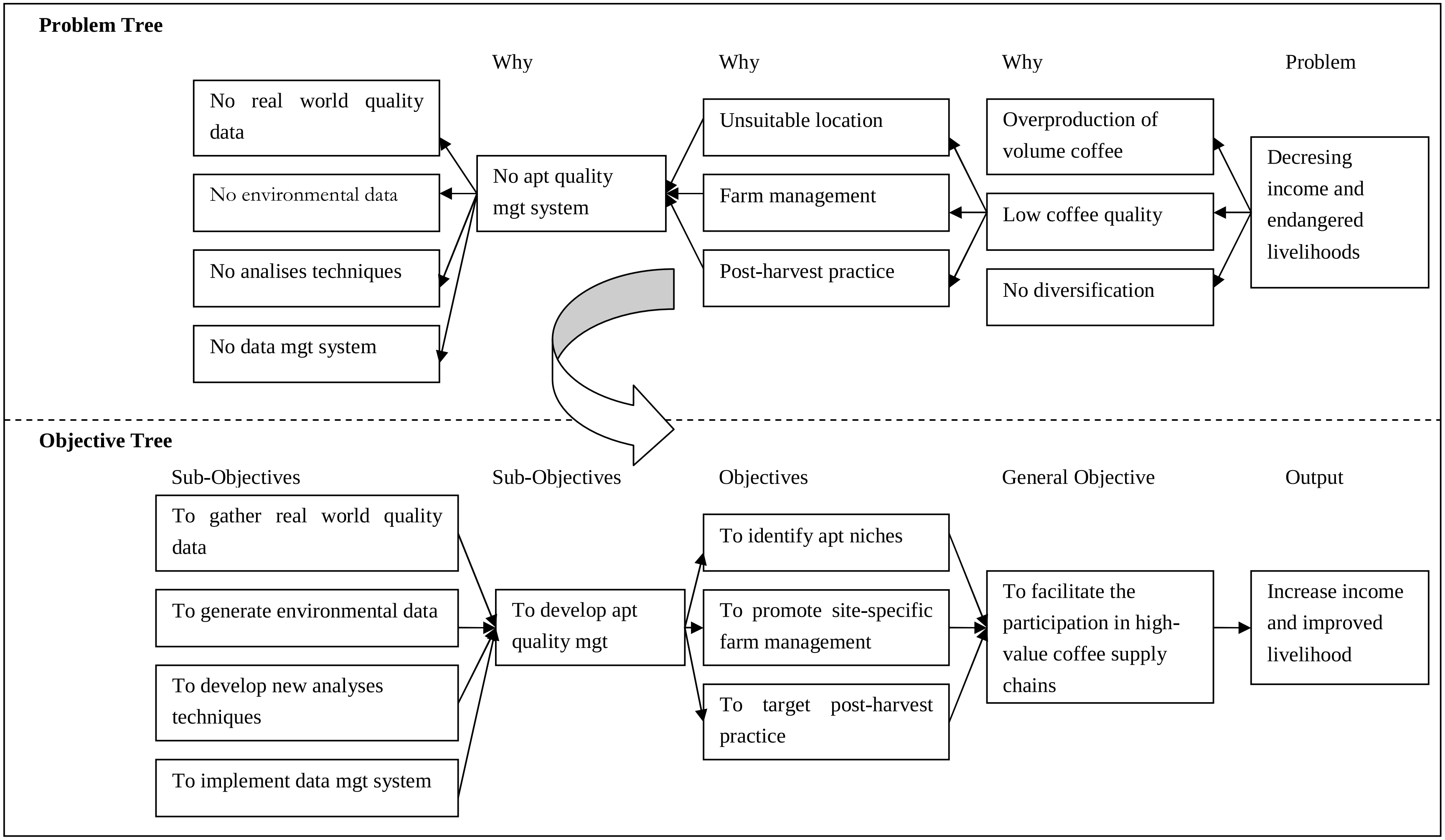


Figure 5: Problem and objective tree.

2 CONCEPTUAL FRAME WORK

2.1 Specialty coffee quality

As stated in Section 1.1 is quality a measure of the extent to which customer requirements and expectations are satisfied and consumers' perceptions and attitudes define which aspects of a product is critical to consumer value. Moreover, quality relates to the fulfillment of requirements through a set of inherent characteristics.

2.1.1 Paradigms

In the conventional coffee trade, as for example implemented by the New York Board of Trade coffee exchange (NYBOT, 2005), coffee quality is measured comparing critical product characteristics such as bean defects (Table 1) or bean grain size with technical specifications for the product. For example, to qualify as Exchange grade coffee, 9 to 23 full defects are permitted, and 50% of the coffee by weight must be above screen 15, and only less than 5% below screen size 14. Exchange grade is defined by the Common Code for the Coffee Community 4C (CCCC, 2005) as those "with minimum size of aggregated volume of green coffee of at least one container". This is the conventional paradigm for volume coffee.

Table 1: NYBOT classification system
The numbers of full defects allowed for each class.

Class	NYBOT grade
1	Specialty grade (0 - 5 full defects)
2	Premium grade (6 – 8 full defects)
3	Exchange grade (9 – 23 full defects.)
4	Below Standard grade (24 – 86 full defects)
5	Off grade (more than 86 full defects)

Specialty coffee refers to class 1 according to the NYBOT grading systemCustomers of high quality coffees assume that their product complies with certain specifications, but they most importantly demand that their product has distinct attributes in flavor, body or fragrance. To classify for specialty coffee SCAA terms: "Coffee beans roasted to greatest flavor potential, brewed to established standards. In the green bean phase it has no defects and has a distinctive character in the cup." The grain size is not considered as decisive for quality, but screen sizes are not allowed to be mixed because when milling and roasting mixed screen sizes have different quality characteristics. In the high-quality coffee markets product specifications are still important (Table 2).

Table 2: Differences between exchange and specialty grade are shown

Exchange Grade (9 – 23 f.d)	**Specialty Grade (0 – 5 f.d)**
Primary defects permitted; 50% by weight above screen size 15, less 5% than 5% below screen size 14	No primary defects; 5% above below indicated screen size
No faults permitted, 5 quakers[1] permitted	No faults and taints; no quakers
Sound cup; good roasting	Must possess at least one distinctive attribute in the body, aroma, or acidity

[1] Quakers are defective coffee beans that fail to roast properly, remaining stubbornly light-colored.

2.1.2 Quality perceptions

Producers, exporters and roasters in the supply chain for specialty coffee perceive quality differently. Their distinct understanding of quality and language used to describe quality is demonstrated with the results of interviews conducted with the actors of the supply chain of specialty coffee (Bode et al., 2006).

Producers refer to quality as:
"…the coffee should be bright, without black beans, very clean, the sieves where the coffee is screened maintained, and that only ripe cherries are harvested…"
(Doña Carmen, grower Ecuador)

"… the coffee has no defect neither a tiny one nor a big one…."
(Don Gilner, grower Colombia)

"… an elegant management…"
(Wife of Don Denis, grower Colombia)

Growers perceive the quality of their coffee mainly based on the color and size of the bean, by the odor and the contamination with defects. Tangible indicators are used for good processing, such as color and time of the fermentation process, and the color and hardness during the drying stage of beans.

On the other hand specialty exporters and roasters define quality as follows: "Quality is a compound of quality attributes, physical and intrinsic quality, organoleptic quality, which is the flavor, the aroma, the acidity, the sweetness, that will satisfy the consumer, and a specific client who is looking for a certain quality profile." (Colombian Specialty Coffee Exporter)

"For me the principal component of coffee quality is the flavor. If the coffee is free of defects, naturally sweet, and if it offers clear and articulated aromas, then I refer to quality." (United States specialty coffee roaster)

"It is not only the absence of defects …the focus has to be in positive attributes". (United States specialty coffee roaster and importer)

"It needs to consist of outstanding aromatic attributes, which are especially fine, especially lively. These are my definitions; I guess that others look more for body or sweetness. The elementary factor for me is the vitality."
(German specialty coffee roaster)

For specialty coffee roasters, the organoleptic qualities, which are intrinsic to each coffee, are decisive. Despite this, the prerequisite for a specialty coffee are the absence of defects. On the other hand are growers' definitions mainly based on objective and tangible attributes. Usually growers do not know the organoleptic quality of their coffee, since they sell the best quality and consume the defective beans. The intrinsic liquor characteristics require skill and training to measure, which few growers have, and this usually implies asymmetric information between buyer and seller (Stiglitz, 1986). In order to improve equity and understanding of quality in the supply chain all the actors need to be able to communicate and discuss quality. The obstacle is not only due to language barriers but also rather due to the very distinct perceptions of quality between the different actors.

2.1.3 Definition

Based on the SCAA specialty coffee definitions, Schröder's definition (2003), the perceptions of quality in the supply chain and on my own experience, the following definition for specialty coffee is proposed:

Specialty coffee is a coffee of a particular production environment (natural environment, agronomic management, and post-harvest practice), which represents characteristics intrinsic in the sensorial quality that is sought of by the market.
This definition of specialty coffee includes three components, the production environment that give (i) a distinct characteristic to the coffee expressed in (ii) the cup quality sought of by the (iii) market. (Läderach et al., 2006)

2.2 Precise quality management

The conceptual frame work will demonstrate how to manage intrinsic quality characteristics for high-value specialty coffees. The aim is to identify and manage the variability in order to produce coffee that meets defined goals. The four-stage approach to variability (Cook et al., 2006) is the conceptual framework where the different theoretical concepts are incorporated and tested for their suitability to manage variability in the supply chain for specialty coffee. The four-stage approach to variability helps to clarify if the different concepts are suitable to identify and generate the information that is required for decreasing variability, which are then compared against the current (traditional) situation. Table 3 shows the chapters of this thesis where the concepts are tested in case studies. The approach stresses the importance of presenting concepts for decreasing variability that pass tests of viability, novelty, actionability and deliverability.

Table 3: The four-stage approach to variability
The concepts applied are built into the approach. Reference is made to the chapters of the thesis where the relevant concepts are tested in case studies.

Four-stage approach to variability	**Thesis chapters**
I: Are the concepts viable?	
-> Concept of comparative and competitive advantage	6
-> Pareto principle	4, 5
-> Identification of limiting factors	4, 5, 6
II: Is the information novel?	
-> House of quality	8
-> New product data	3, 8
-> New environmental data	3
III: Is the information actionable?	
-> Taguchi concept	7
-> Realize the competitive advantage	7
-> New data analyses techniques	3
IV: Can the information be delivered to the stakeholder?	
-> New feed back mechanisms	3
-> New information management	3

2.2.1 Viability of concepts

As statetd in Section 1.2 is high variability in coffee quality problematic and can endanger income. Therefore it is important to develop concepts that will lead to the generation of information that decreases that variability. That is, the approach must show that the concepts and the information they generate will remove a major source of variability and in doing so will be beneficial for the actors in the supply chain by reducing uncertainty.

Concept of comparative and competitive advantage

Two important concepts in international trade theory are competitive advantage and comparative advantage, which are conceptually different but are interrelated. Comparative advantage refers to the potential advantage that one entity (area or company or some other such entity) has over another for the production of a specific product. Competitive advantage, on the other hand, refers to the factors that explain why an entity is able to realize its comparative advantage (Borregaard and Dufey, 2005). For example, according to both empirical analyses and expert knowledge, the farmers of the southern Colombian municipalities of El Tambo-Timbio and Inzá have the environmental prerequisites to produce high quality coffees. In this case, these farmers have a comparative advantage compared to other farmers in the same department. However not all the farmers in these two municipalities take the advantage of their favorable prerequisites to produce the specialty coffee that commands a premium price in the market. So while all the farmers in these high quality niches have a comparative advantage over other farmers in the Department, some do convert this into a competitive advantage, and other dont. The question then becomes, "Why is farmer X able to turn his comparative advantage into a competitive advantage while his neighboring farmer Y does not?" That "*why*" question then leads to the further questions "*What* is farmer X doing differently and *how* is he doing it".

Pareto principle

What are the factors that farmers need to manage and control in order to decrease variability? The volume coffee industry has a naïve approach to quality control, using merely one final sampling inspection to screen for non-conformance to the grading standards (see Table 1). Using this approach, the only way to obtain higher quality is by increasing sampling frequency and so increasing the costs of inspection. Over the last few decades, however, the quality interventions have moved from a focus of inspection to a focus of prevention (Lee and Whang, 2005), or, as stated by (Robinson and Malhotra, 2005), a shift from product control to process control. Quality control systems in manufacturing industry are based on the Pareto Principle.

Vilfredo Pareto was an Italian economist who described that the income of the population is unequally distributed. Few people in a community, the vital few, earn a larger part of the total income while the majority, the trivial many, earn a smaller fraction. Later Pareto's Principle was translated to industry, with totally universal application. The Pareto Principle states that causes and effects are not linearly and proportionally related, that is a few causes produce the majority of effects. This is also known as the 20-80 law: 20 percent or fewer causes produce 80 percent of the effects (Figure 6). The 20-80 law holds true in many industrial situations of quality control and is believed to be applicable to quality management in agricultural production. The goal, then, is to identify the critical few factors that contribute most to variation in quality with the objective that by controlling them, variability around an overall target objective can be reduced.

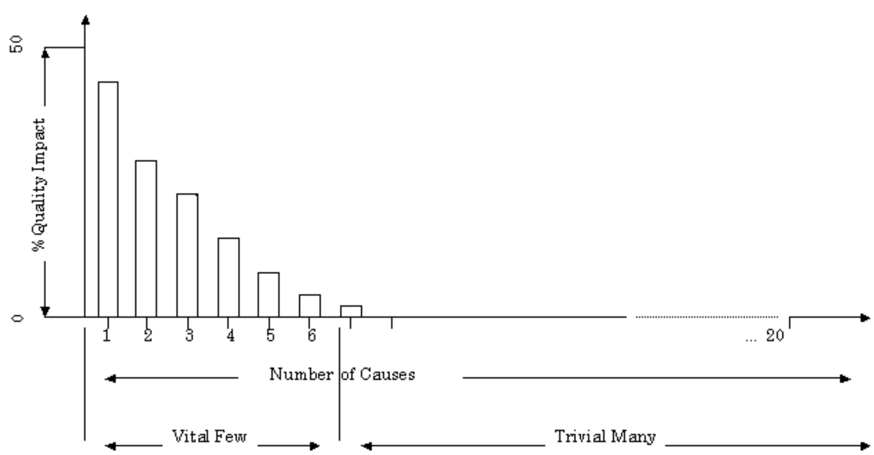


Figure 6: The Pareto Principle.
Only few causes produce the majority of the effects. (Adapted from (Bhote and Bhote, 2000).

Identification of limiting factors

The first step to identify the environmental factors that affect coffee quality is to review literature of studies conducted in other growing areas. Environmental factors that affect coffee quality are spatially correlated, that is, the environment changes over space and as it does, quality also changes. The objective is to define the relation between quality data and the parameters that describe the environment. There are three different types of spatial statistics:

- Point correlations and regressions compare data of sample sites;
- Cell correlations, compare cells of occurrence data; and
- Moving Window correlations compare sites (pixels) taking into account information from surrounding pixels.

In addition, spatial decision support (SDS) tools can be used to identify limiting factors. There are various SDS tools based on different algorithms ranging from Bayesian statistics, artificial intelligence, maximum entropy, and so on. The effect of controlling agronomic management and post-harvest factors can be determined by carrying out formal experiments on-farm.

2.2.2 Novelty of information

To be useful, any new information generated and compiled must be perceived by actors in the supply chain as offering new insights from that, which is currently available. Volume coffee requires very few items in the specification; usually traders and roasters only know the variety, country or region of origin, its altitude in general, and some basic quality indicators such as percent of defects and grain (sieve) size. Information on the relation between quality and the production processes is not available so that the incentive to improve the characteristics that contribute to the quality of the product is almost entirely absent. In contrast, management of the quality of specialty coffee requires information on both production and processing sides to define the product more closely. The interactions between quality and the natural, agronomic and processing components of the production environment require that these quality predictor variables be known as well as the response variables, such as the quality characteristics sought by the market.

The house of quality

For the success of a product it is crucial taking into account the customer perception, which is referred to as the “voice of the customer” (Lowe and Ridgway). Quality function deployment (QFD) is a set of tools to translate customer requirements into the appropriate technical requirements for each phase of production. QFD builds on the "voice of the customers" to asses the demand and uses a comprehensive matrix, the house of quality (HOQ) for documenting information, perceptions and decisions (Akao, 1990). The HOQ is the centerpiece of the QFD. In the HOQ the customer's requirements are related to the product characteristics, so that it is crucial to match the product to the requirements of the market. In the case of the supply chain for specialty coffee the "voice of the customer" is the cupper, a skilled person with trained sensory perception. These experts are persons "with considerable experience and proven ability in sensory assessment of a given product under specific conditions"(Land and Shepherd, 1984). The cupping evaluation is the HOQ where quality traits are identified and then related to components of the production specifications such as district of origin, shade, varieties, and post-harvest practices.

New product data

The lack of relevant agricultural information is usually the lack of its site specific focus and the relevance for the industry (Cook et al., 2006). For quality management in supply chains, however, these are two vital components. Because coffee quality is site specific, data must be collected from individual sites to understand the interactions between the production environment and the quality assessment. Moreover, because the assessment must be based on industry standards, the data have to be those provided by the industry.

A specific evaluation is needed for quality assessment of specialty coffee. The cupping evaluation of coffee flavor has three components: olfaction (aroma of the freshly ground coffee and the flavour of the brew), gustation (the taste sensations of the brew), and mouthful (the feel of the liquid in the mouth) (Lingle, 2001). Sensorial coffee assessment is performed by experts who in the specialty coffee sector usually are cuppers and importers at the same time. Experts are persons "with considerable experience and proven ability in sensory assessment of a given product under specific condition (Land and Shepherd, 1984). Cuppers represent the markets and their judgment impacts on management, purchasing, processing and marketing decisions (Gatchalian, 1981). The cupping process is the central component of the HOQ and with the other QFD tools brings together consumers, traders and representatives of the grower associations to make sure that the voice of the customer is transmitted upward along the chain. This approach makes sure that the information generated is relevant to the problem, especially as the cupper is a person from the industry who represents the market and sets the standards. The information from the process is production specific, close to real time, driven by the market and is therefore relevant and unique to the problem.

New environmental data

Over the last few decades there has been a data revolution that provides more data on environmental variables at a higher resolution, both temporal and spatial, for the whole globe. The three principal advances are for higher resolution topography, climate and vegetation data. These include:

- Shuttle Radar Topography Mission (SRTM): High resolution terrain model (90m spatial resolution, improving to 30m). Processed and downloadable from http://srtm.csi.cgiar.org (Jarvis et al., 2004)
- WorldClim: 30 arcsecond (about 1 km at the Equator) spatial resolution climate data. Processed and downloadable from http://www.worldclim.org (Hijmans et al., 2005a).
- MODIS: High temporal resolution thermal and spectral imagery providing global images of vegetation every 16 days, with a spatial resolution of 250m.
- Satellite imageries of different spatial resolutions; 30 m (Landsat) and 0.60 m (Quickbird) resolution.

2.2.3 Actionability of information

The test of “actionability”, that is whether any particular piece of information is, of itself, sufficient to justify recommending a course of action, is perhaps the hardest to satisfy. The tests of significance and novelty specify the potential importance of the new information, while actionability addresses whether the information can be put to practical use. The Taguchi concept is useful in this regard.

Taguchi concept

In manufacturing, the information that is gathered about a product is specific for each of the conditions under which the product was produced. The measured factors explain the quality of the product within its defined environment. This information permits the analysis of the variation of the quality of a product around a given target quality and through a cyclic process of trial and error allows minimizing the variation according to the Taguchi concept. Taguchi started from the realization that in much industrial production, outcomes need to be produced to meet a given target specification. He also realized that excessive variation lies at the root of poor manufacturing quality. He argued that quality engineering should therefore start by quantifying the cost of poor quality. In much conventional manufacturing the cost of poor quality is represented by the number of items that lie outside a given specification multiplied by the cost of reworking or scrapping the products that fail to meet it. It is self evident that losses become very small when there is little variation from the target specification. Taguchi proposed to find a useful way to describe these losses with statistics. He specified three situations:

- The larger the better (for example, agricultural yield);
- The smaller the better (for example, carbon dioxide emission); and
- On-target production with minimum-variation (for example, specialty coffee production that complies with consumer requirements and earns a premium)

The cyclic learning process is adapted from Taguchi as follows: Consider the factors that drive an agricultural production system where: some are controllable by the supply chain members others are not (Figure 7). With no control system in place, a product with great variation in quality is produced, shown by the dashed line, while the objective is to produce a product with a consistent quality as shown by the solid horizontal line. With a suitable control system, the contribution of controllable factors towards variation in product quality can be estimated by the chain members applying their own knowledge or other sources of information. Based on these estimates a control or damping system can be implemented to reduce the variability in quality as shown in the dotted line. The approach is based on cycles of analysis and learning and comprises four stages, information acquisition; interpretation; evaluation; and control (Cook and Bramley, 1998). This approach is applied to the supply chain for specialty coffees in the following sections.

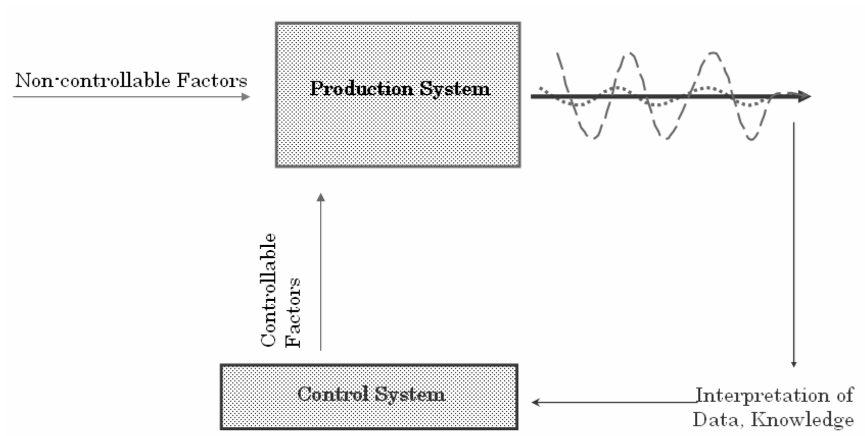


Figure 7: The agricultural production system in the process control concept.
Interpretation of product quality is done so that controllable factors can be identified and managed (Oberthür et al., 2005).

Realize the competitive advantage

As described above, many farmers do have comparative advantage over others but do not convert this to a competitive advantage. To address this issue, farmers must choose those farm management practices that permit the full expression of the natural-resource base, that is those environmental conditions that identify specific niches. Once farmers have the information that identifies their specific niche, they can make that information actionable by implementing a version of the Taguchi system of cyclic process control.

The process requires that the growers obtain cupping information on the effect of different environmental factors and management practices, such as aspect, soils, shade management, harvest time, and post-harvest processes. In this manner, growers convert their farms into applied research sites. They then know what influence different management conditions have on cupping quality and thus what are the conditions for increasing the quality of their product and eventually obtaining a price premium.

The management practices to achieve this will likely be different for each location that is management will be site-specific. This implies that participation in supply chains of high value products must be process oriented as opposed to product oriented as in the market for bulk coffee. Moreover, the configuration of the supply chain is an iterative process, which inevitably includes failures as well as successes (Robinson and Malhorte, 2005).

New techniques for data analysis

The development of computer hardware and software has allowed the evolution of new techniques for data analysis and data mining. Artificial intelligence (AI), new statistical algorithms, spatial analyses, and geographic information systems (GIS) provide information on the occurrence of spatially-distributed patterns of attributes, which were hitherto not possible. Predictions that operate on the basis of the state of a particular property, such as coffee quality that may be difficult to measure directly, can be inferred from the state of other, measurable entities and knowledge of their interrelationships (Fraisse et al., 2006). In the case of coffee, environmental factors can be used to infer potential cupping quality (Läderach et al., 2005).

2.2.4 Deliverability of information

Having demonstrated the potential demand for information, the final test is to consider the practicalities of delivering that information to the user. There is increasing recognition of the importance of providing free access to information to a very wide range of potential users along the supply chain.

New information management

A supply chain is a “system of suppliers, manufactures, distributors, retailers and customers where material, financial and information flows connect participants in both directions” (Fiala, 2005). Supply chains usually contain four entities: At the start of the chain the suppliers, followed by the manufactures, and distributors and finally the customers (end users). The supply chain for coffee consists of growers, traders (exporter and importer), the roaster and the consumers. Supply chains for specialty coffee tend to be shorter because the importer is often the roaster as well.

The requirement to provide free access to the wide range of potential users implies that there both material (in the form of product and samples) and information flows will become increasingly complex. Moreover free flow of information and material is essential to the successful production and marketing of high value products on the international markets. The increasing complexity and extra dimensions of these flows will require new information-management technology deployed in a central information management system to ensure that all actors in the supply chain have access to the information that they need. Furthermore, it is important be able to trace a particular product and its related inforamtion back to its site of origin. As part of the work associated with this thesis, colleagues created CInfo, a web-based system for information management of high value agricultural products (Niederhauser et al., 2007).

New feed back mechanisms

Growers involved in the project, typified by smallholder growers association in San Roque municipality in the Huila Department of southern Colombia, are learning to use quality to improve their product. They harvest their plots separately and have them cupped at the cost of about US$1.00. The quality assessments allow them to decide on which market to sell their parchment beans. If the beans are of outstanding quality they sell them to a specialty exporter, if the quality is good, but less than outstanding, they sell them as fair trade coffee, and if the quality is low they sell them as volume coffee. The results of the quality assessment are stored in the Cinfo database and farmers use the information to improve their farm management. In the case of repeated defects the associations' own technician visits the grower's farm to identify potential mismanagement that might cause the defects in question.

2.3 Analytical frame work

To test if enabling farmers to engage in differentiated markets by selling high- valued products increases their income and improves their livelihoods, the question may be posed as: Is the livelihood that people derive at location *i* a function of the income generated from quality product *q*?

$$LIV_i = f\ (INC_q) \qquad (1)$$

Where:

LIV = livelihood, and

INC = income generated by a quality product.

To do so, they must deliver products of higher quality; where quality at location *i* is defined by its sensorial attributes.

$$INC_q = f\ (QUA_i) \qquad (2)$$

Where:

QUA = quality.

Location *i* and its agronomic and post-harvest management are drivers of quality.

$$QUA_i = f\ (MGT_i) \qquad (3)$$

Where:

MGT = management.

To improve livelihoods of coffee producers the agronomic management at location *i* needs to be adapted in such a way as to maintain the quality produced at the location.

$$LIV_i = f\ (INC_q) = f\ (QUA_i) = f\ (MGT_i) \qquad (4)$$

2.4 Operational model

The operational model (Figure 8) outlines how the research was conducted. First, the environments (natural environment and production environment) are described and factors determining quality characterized and their impact quantified. Secondly, tools and methods are developed to turn the farmer's comparative advantage into a competitive advantage. Thirdly, products derived are presented, evaluated and validated. Finally the conclusions and recommendations chapter points out future investigation to further fine-tune the models and concepts developed.

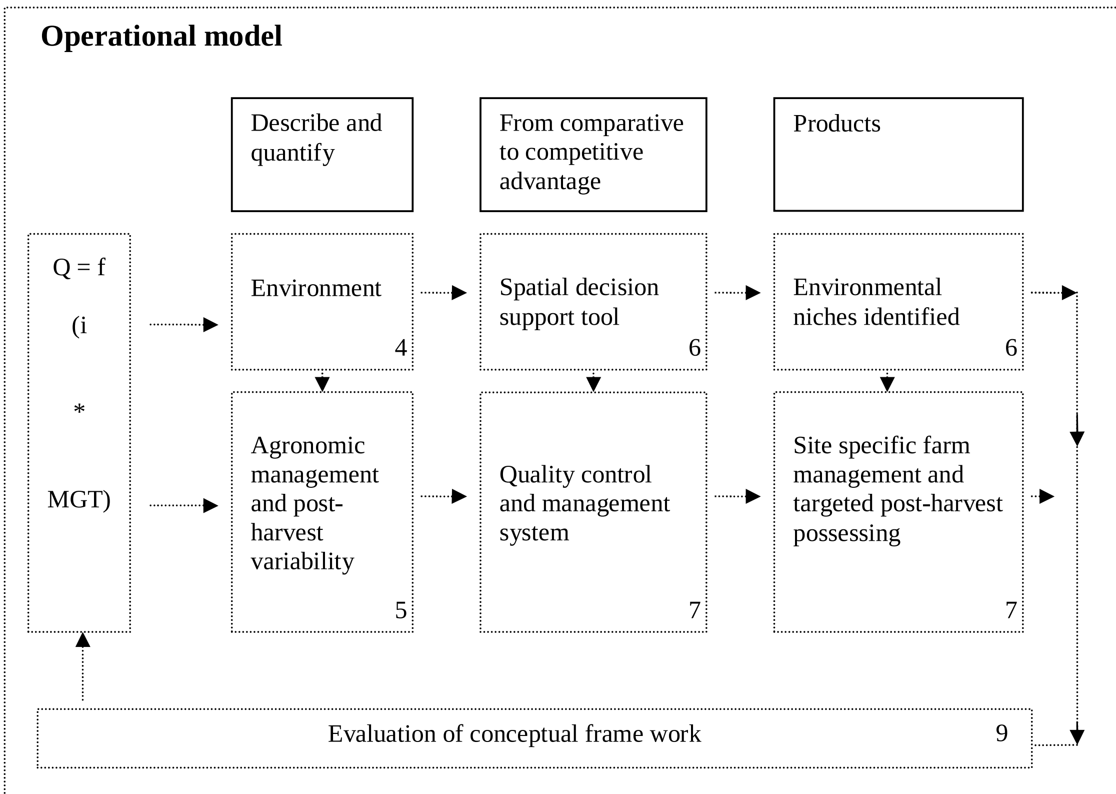


Figure 8: The operational model.
The numbers in the boxes indicate the chapter of the thesis where the topics are presented.

3 METHODOLOGY

The methodological framework is divided into the sub-chapters describing sites and sampling (3.1), data generation (3.2) analytical methods (3.3) and design and outline of the analyses (3.4). The research consist of studies at two different geographical scales; small-scale studies that mainly build on GIS-generated data and information gathered through interviews, and large-scale studies that build on empirical measurements. Small-scale studies are referred to as the *Exploratory Study* and the large-scale study as the *Case-Control Study*.

The case-control study includes several sub-studies addressing the impacts on coffee cup quality of aspect, soil fertility, shading, fruit load, targeted harvesting, harvest per canopy, time of harvest, fermentation and drying practices. Case-control studies provide point data for individual cases and their relation with a set of controlled variables. Exploratory studies use aggregate geographical data to investigate spatial relationships and interactions between variables; they are usually quicker and less expensive to do than case-control studies. Table 4 gives an overview of the samples and methodologies used for the different studies. Some studies did overlap and use partly or entirely the same data sets. Figure 9 shows a visual representation of the spatial distribution of the sample sites used in the exploratory and case control studies

CInfo is an online data warehouse system that was developed to administrate the incoming data. Farm and production data are stored in a relational database, allowing consistent storage and dynamic linkage of data. CInfo manages farm data, including the description of the management units (e.g. GPS coordinates), field data (e.g. varieties and shade system), harvest (e.g. harvest date, lot quantity, and certification), post-harvest processing, and sensorial and physical coffee-quality data. All participants of the supply chain are able to insert and to query their data on a daily basis and assure that the information is up-to-date.

3.1 Sites and samples

Exploratory studies were conducted in Colombia and Honduras. In Colombia samples were collected in the municipalities of Inzá and El Tambo-Timbio in the Cauca Department and in Honduras in all major growing regions. Case-control studies were conducted in the municipalities of El Tambo-Timbio and Inzá in the Cauca Department, in the Concordia municipality in the Antioquia Department of Colombia and in the municipalities of El Encinal and Axocuapan in Mexico (Figure 9).

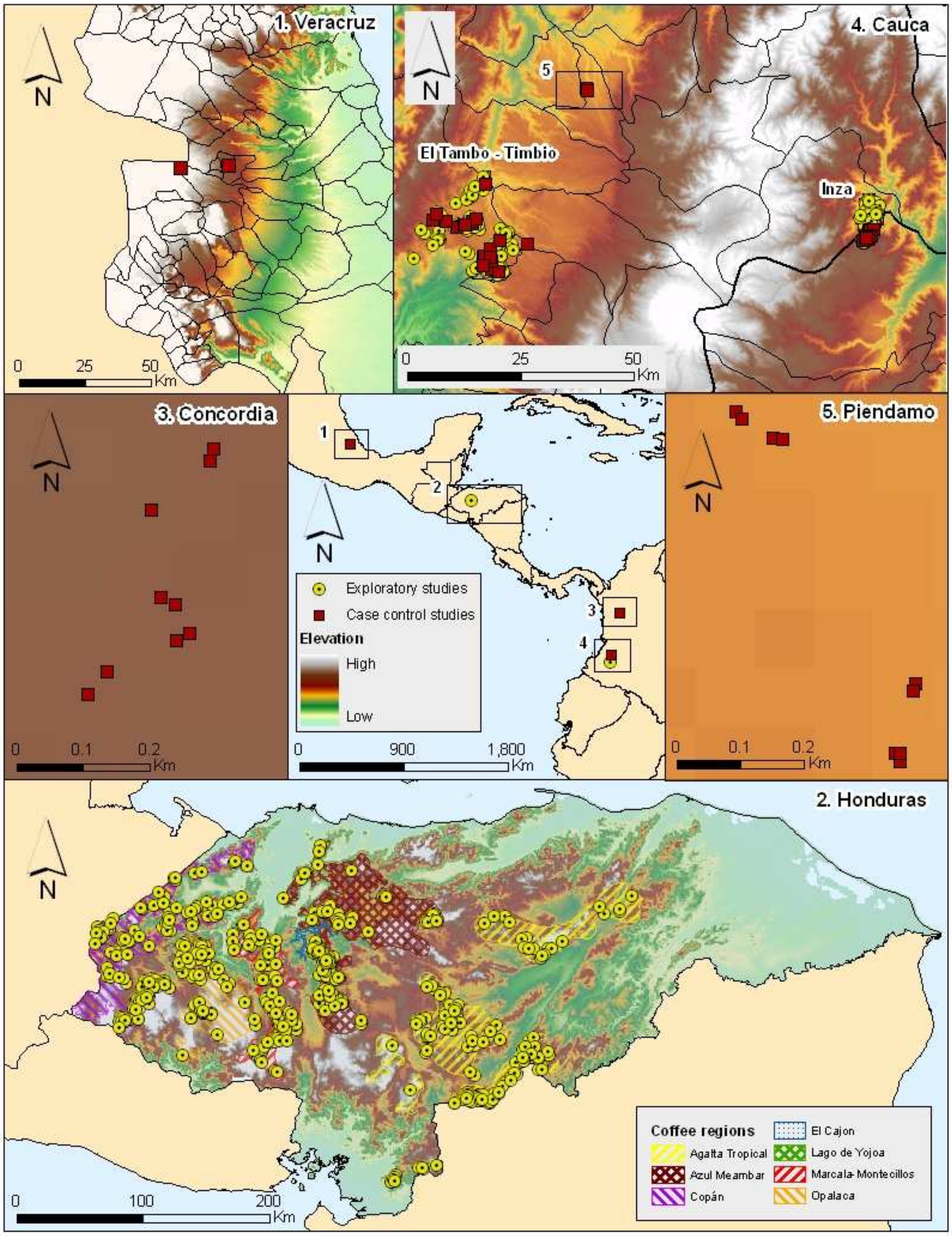


Figure 9: Exploratory and case-control studies sampling sites.

Table 4: Overview of objectives and studies

Sub-Objectives	Sample sites	n	Sample type	Analyses	Study type	Chapter
1. To describe and quantify the impact of the natural environment on coffee liquor quality.	Honduras Cauca	582 88	o.f. producer[1] o.f. standardized[2]	Correlation, cluster analyses, spatial visualization.	Exploratory	4
2. To describe and quantify the impact of agronomic management and post-harvest processes on coffee liquor quality.	Cauca	270	o.f. standardized	Spatial visualization and description	Exploratory Ag mgt[3]	5
	Cauca	74	o.f. standardized	Correlation and description	Exploratory Php[4]	
3. To present, compare and test spatial analyses tools for the identification of high quality coffee niches.	Honduras Cauca	582 88	o.f. producer o.f. standardized	BioClim, Domain, Maxent, CaNaSTA, Kappa, ROC AUC, MacNemar	Exploratory	6
4. To develop and test concepts of site specific agronomic and post-harvest management practices for improved coffee quality.	Piendamo (Cauca) Inzá (Cauca) Concordia (Antioquia) El Encinal (Veracruz) Axocuapan (Veracruz)	139 33 76 97 48	o.f. standardized o.f. standardized o.f. standardized o.f. standardized o.f. standardized	ANOVA and correlation	Case control Ag mgt	7
	El Tambo-Timbio (Cauca) Inzá (Cauca)	56 32	o.f. producer o.f. standardized	Test of significance and correlation	Case control Php	
5. To determine the utility of qualitative quality control methods.	El Tambo-Timbio (Cauca) Inzá (Cauca) Timana (Huila)	52 52 59	o.f. producer o.f. producer o.f. producer	Discriminate analyses, principal component analyses and test of significance	Case control	8

[1] o.f. producer = on farm producer samples are entirely commercial samples; [2] o.f. standardized = on farm standardized samples are commercial samples with controlled post-harvest processment; [3] Ag mgt = Agronomic management; [4]Php = Post-harvest processing

3.1.1 Exploratory study

Field sampling design

Ideally one would have wished to apply some kind of probability sampling, using either a model-based or a design-based approach (Brus and De Gruijter, 1997; Dobermann and Oberthur, 1997) on which to implement the selection of sites in the exploratory study. Probability sampling means that every element, or sampling unit, of a population has a known probability of being included in the survey sample, so that once the population is defined, sampling sites are selected randomly. However operational constrains, such as timing and length of the harvest, long travel times to the field sites, availability of processing equipment and field support, location of farms and accessibility to them given the time constraints, prevented the implementation of strictly random sampling. Instead the strategy adopted was to use sampling based the subjective criteria of prior experience, convenience and feasibility.

There are two broad non-probabilistic sampling methods, accidental, typified by the “man in the street” opinion-seeking and purposive, where the need is for a targeted sample and where sampling for proportionality is not the primary concern. Because the study objective was well defined, purposive sampling was used here. There are several strategies on which to base purposive sampling including modal instance, expert opinion, quota, heterogeneity and snowball sampling.

Proportional quota sampling, which was used here, attempts to represent the major characteristics of the population by sampling proportional numbers of each category. In contrast, in non-proportional quota sampling one specifies the minimum number of sampled units required in each category. In this study, the purpose was not to have numbers in each category that exactly matched their proportions in the whole population, but to have enough samples to ensure that the most important groups in the population, identified by expert opinion, were represented. This method is the non-probabilistic analogue of stratified random sampling, which is typically used to assure that smaller groups are adequately represented in a sample.

The major difference between non-probabilistic and probabilitistic sampling is that non-probabilitic sampling does not involve random selection. But this does not necessarily mean that non-probability samples are not representative of the population. But it does imply, however that non-probabilistic samples cannot depend upon the rationale of probability theory, and therefore must find other ways to show that the population was adequately sampled. Traditionally researchers prefer probabilistic or random sampling methods over non-probabilistic methods, considering them more accurate and rigorous. However, in much applied research, such as the project that is reported here, there are often circumstances where it is neither feasible, practical nor theoretically sensible to undertake random sampling.

The difficult issue in purposive quota sampling, as used here, is to decide upon the specific characteristics on which the quota will be based. In Colombia, literature review, prior knowledge generated by colleagues' similar work in the Cauca Department and consultation with other experts, expert knowledge of local coffee committees were used to identify sample farms. The objective was to choose farms that represented as broad a range of conditions as reasonably possible, including those thought to have the potential to produce high-value coffee. In Honduras special emphasis was laid on sampling different sized farms in each zone.

Site characterization

The study sites in Cauca Department were mainly in the municipalities of El Tambo-Timbio and the municipality of Inzá with a few sites selected in other municipalities.

Table 5: The five major coffee growing regions of Honduras

Region	Departments	Altitude (masl)	Annual precipitation (mm)	Mean annual temperature (°C)	Main coffee varieties
Copan	Ocotepeque, Lempira, Cortés	1000-1600	1800-2200	18-22	Bourbon, Caturra
Opalaca	Santa Barbara, Intibuca, Lempira	1000-1400	1800-2200	18-22	Caturra, Catuai, Typica
Montecillos	La Paz, Comayagua, Santa Barbara, Itabuca	1200-1600	1700-2200	16-20	Typica, Bourbon, Caturra
Azul Meambar	Yoro, Comayagua	1000-1300	2000-2500	18-22	Bourbon, Caturra, Catuai
Agalta Tropica	Olancho, El Paraíso, Franscisco Morazan	1100-1300	1700-2300	18-24	Bourbon, Caturra

The farms in El Tambo-Timbio are at an altitude of 1400 to 1750 masl, with an annual precipitation of 1900-2300 mm, and a mean annual temperature of 17-19°C. The farms in Inzá are higher (altitude 1700 to 1850 masl), somewhat drier (annual precipitation 1580- 1760 mm) and cooler (mean annual temperature 16.6-17.7°C). In Honduras the five major coffee growing regions were sampled (Table 5).

3.1.2 Case control study

Site selection and characterization

The philosophy of the approach is that farmers manage only those factors that make good sense environmentally and commercially. This can be one or several factors depending on the particular farm and farmer. The studies were therefore conducted on commercial farms, which provided diverse conditions for the implementation of various managerial scenarios and which differed in their complexity. The farms included in the study were based on the willingness of growers and their supply-chain partners to take part in the research.

Specifically, the study examined two estate farms (> 25 ha) and 62 small farms (0.5 – 5.0 ha) in Colombia; and two farms of about 5 ha in Mexico (Figure 9). One of the estates in Colombia was located in the municipality of Concordia (longitude -75.89; latitude 6.03; 1870 masl, Department of Antioquia) and the other in the municipality of Piendamo (longitude -76.57, latitude 2.75, 1640 masl; Department of Cauca). The small farms were located in the municipalities of Inzá (33 farms, longitude -75.99-76.02, latitude 2.47-2.53, 1630-1990 masl; Department of Cauca). The two Mexican farms were located in the state of Veracruz. One farm was in the community of El Encinal (longitude -96.82, latitude 19.21, 890 masl) in the municipality of Totutla and the other in the community of Auxcuapan (longitude -96.98, latitude 19.20, 1490 masl) in the municipality of Tlaltetela. Departments in Colombia represent the same administrative level as the states in Mexico but communities in Mexico are one administrative level lower than the municipalities in Colombia.

3.2 Data generation

The data generation process is divided into exploratory data, case control data and quality data.

3.2.1 Exploratory data generation

Generation of biophysical variables

In a review of the literature, environmental factors that impacted most on beverage quality were identified and subsequently generated from a number of different sources. The ten factors chosen were: Mean annual precipitation, number of dry month per year, mean annual solar radiation, mean annual temperature, mean annual dew point, mean diurnal temperature range, altitude, northness, eastness (see equations (5) and (6) below), and slope. For all GIS manipulations and mapping ESRI GIS software and DIVA GIS (Hijmans et al., 2005b) were used. The environmental factors were mapped as rasters or grids, where a raster is a type of map used to represent continuous layers. The mapped areas were divided in equal size cells (pixels), in which each pixel contains a single value of the factor mapped. When data were presented in raster, rather than vector format, it was convenient to refer to resolution rather than to scale (O'Brien, 2004). Resolution refers to the size of one pixel on the ground, and is commonly measured in km or degrees (or subdivisions of these). The distance represented by one degree of longitude varies with latitude, and is about 111km at the equator. A 30 arc second resolution is often referred to as a 1km^2 grid, and 3 arc second resolution is approximately equivalent to a grid of 90m.

Climate data were extracted and mapped using WorldClim (WorlClim, 2007) and MarkSim data. WorldClim is a global database of climate variables in the form of grid surfaces with a spatial resolution of 30 arc seconds. The data layers were generated at this resolution through interpolation of average monthly climate data from some 46,000 weather stations (Hijmans et al., 2005a). MarkSim uses data from 20000 climate stations. It uses an interpolated climate surfaces with 10 arc minute resolution and uses a third-order Markov model with stochastic resembling of the model parameters to estimate climate data for the tropics (CIAT, 2007; Jones et al., 2002). The variables extracted and generated from Worldclim and MarkSim were: Monthly total precipitation, monthly mean, minimum and maximum temperature; annual precipitation, annual temperature, and dry months per year. Annual average of diurnal temperature range was calculated from WorldClim MetGrid. Because relative humidity varies diurnally with temperature, while dewpoint, the temperature at which air becomes saturated, varies relatively little diurnally. When the relative humidity is high, the dew point is closer to the current air temperature. Dew point was used to was used to represent the variation in atmospheric humidity between seasons and maps of it were calculated (Linacre, 1977) from the WorldClim dataset. Since solar exposure is difficult to calculate, mean annual insolation, which is the incoming solar radiation was calculated from MarkSim (Donatelli and Campbell, 1997).

Terrain attributes such as elevation, aspect and slope for the study areas were generated from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) using Esri GIS software. Northness and eastness (equation 5 and 6) were calculated from the aspect information (Zar, 1999). The SRTM is a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). In February 2000, the space shuttle produced digital topographic data for 80% of the Earth's land surface using radar interferometry. These data were mapped as a DEM, which is a raster file containing spatial elevation data. The data are of very good quality with 3 arc second resolution. At CIAT, the holes in the primary coverage have been filled with secondary data (Jarvis et al., 2006).

$$\text{Northness} = \sin((\text{aspect} * \pi)/180) \quad (5)$$

$$\text{Eastness} = \cos((\text{aspect} * \pi)/180) \quad (6)$$

Soil properties were problematic to map for a number of reasons. Soil characteristics maps do not exist at a large scale for the study areas so they would have had to be derived from coarse-scale maps of soil type. But the scale of maps of soil type, typified by the FAO World Soil Map with a scale of 1:5,000,000, does not generally allow soil heterogeneity to be represented (O'Brien, 2004). Furthermore, soil characteristics can vary a lot at very local scale, and although some general characteristics such as pH and fertility have been derived, there is not usually a direct correspondence between soil type and other important soil characteristics. It was therefore not possible to map the soil characteristics suggested in the literature to impact on coffee quality. The digital version of the soil map of the Colombian Agustín Codazzi Geografic Institute (IGAC, 1983) at a scale of 1:500 000 were used for the description of soil type.

Farm management characterization

Questionnaires were developed for the capture of information on crop management. The questionnaire consisted of three parts: (i) the administrative and geographic description of the farm with its management units (MUs) and personal information about the grower; (ii) description of the post harvest handling processes and the facilities used for processing and; (iii) details of field management practices of each MU. In this context, MUs are defined as land areas that can be independently managed by the grower during all stages of production. An MU can therefore be a single individual field, a group of fields or even a complete small farm. Details assessed in part one of the questionnaire are: Name of producer, farm, location of farm and GPS coordinates; farm size and membership in an association. Details assessed in part two of the questionnaire are: Description of the post-harvest process such as type of machines, times taken in each processing step, and the state of equipment and the working environment. Details assessed in part three of the questionnaire are: Varieties grown, planting dates, planting system and distance between plants, pruning, shade management including, shade trees and planting distances fertilizer application and disease and pest management. For details on the data capturing formats refer to the Annex.

3.2.2 Case control data generation

Selection of biophysical variables and farm management practices

The different biophysical variables and management practices selected are shown in Table 6. The estate farms in Colombia provided the widest choice of management options. Growers identified five different management units in each estate that presented northern, western, southern and eastern aspects. In addition, one plateau (flat slope) MU was also selected. In the MUs with different aspects, two sites were chosen on the upper and lower parts of the slope to give contrasting levels of soil fertility, since growers contend that upper slopes are less fertile than lower slopes. The case control studies for the assessment of the post-harvest practices were conducted in the farms in El Tambo-Timbio and Inzá only.

Table 6: The biophysical variables and management practices examined.
Note that not all variables and practices were represented at all sites

Sites	Biophysical variables and management practices						
	Aspect[1]	Soil fertility[2]	Varieties (#)	Shade	Fruit thinning	Canopy level[3]	Harvest (#)
Concordia	5	2	1	None	50%	3 levels	2
Piendamo	5	2	1	None	50%	3 levels	1
Inzá small farms	VNA[5]	VNA[5]	1	VA[4]	None	Whole tree	VNA[5]
El Encinal	Flat	1	4	VA[4]	None	Whole tree	1
Axcocuapan	Flat	1	2	VA[4]	None	Whole tree	1

[1] Aspect (north, east, south, west and flat; in Concordia northwest instead of north). [2] Soil fertility level (1 = fertile is lower slope position, 2 = infertile is upper slope position). [3] Number of horizontal strata harvested. [4] VA = variable analyzed here. [5] VNA = variable not analyzed here.

In each of the nine identified sites, different harvesting strategies were implemented. These practices were selected after consultation with the growers and included harvesting fruits separately from different tree canopy levels (low, middle, high; in Concordia), fruit thinning (in Concordia and Piendamo) and harvest time (Piendamo).

The first canopy level included the upper orthotropic nodes and comprised leafy primary plagiotropic branches with few fruit-bearing nodes. The middle region comprised primary plagiotropic branches with a large majority of heavy fruiting nodes but with few leaves. The lower canopy region comprised plagiotropic branches that had already produced the previous years and bore secondary and tertiary branches that had few fruiting nodes. The fruit thinning consisted in removing 50% of the fruits nine weeks after the main flowering from 25 previously-labeled trees. At this time the fruits have initiated the bean filling stage and have reached about 10% of their final size (Arcila-Pulgarín et al., 2002). The harvest in Piendamo was divided into an early harvest on 12 May and in a late harvest on 9 June. Other management practices were implemented by the growers using their usual standards.

Managing so many different factors was impossible in the smaller Colombian farms. Farm owners identified one MU in each small farm for the inclusion in the study and shade levels were defined in each of these management units. Other agronomic management practices were very similar in all small farms.

In Mexico aspect, variety and shade levels were determined for eight management units in El Encinal and four management units in Axocuapan. The other agronomic management practices followed local commercial standards but were similar in all the MUs selected in Mexico.

Measurement of biophysical variables

Geographic location was determined using a Trimble Pro-XR GPS with Omni-STAR real-time correction. Aspect in degrees (°) was measured with a compass. Hemispherical imagery to describe shade levels was taken with a NIKON Cool-Pix E4500v1.3 digital camera using a fish-eye lens with a field of view of 180°. The imagery was then processed using Win-SCANOPY (Regentinstruments, 2005) software to derive the illumination parameters. First the pixels of the imagery were classified as canopy or sky, the output of this process is a black and white image. The second step was the analysis of the canopy, which comprises the analyses of the canopy structure and the radiation analyses. The canopy structure variable derived for the present analyses was the gap fraction, which is the number of pixels classified as sky divided by total number of pixels in the image. The shade percentage is simply the numerical complement (1 - gap fraction) expressed as a percentage.

In the radiation analyses the average direct and diffuse photosynthetically active radiation (PAR) over (PPFDO) and under (PPFDU) the shade tree canopy were estimated in $\mu mol\ m^{-2}\ s^{-1}$. PAR radiation is assumed to be constant over time and is further assumed to be a constant percentage (51%) of the solar energy flux. Atmospheric attenuation is inversely proportional to atmospheric transmittance at zenith and relative path length to the zenith. As common in meteorological studies incident radiation was cosine corrected to account for the radiation angle of incidence with respect to the receiving surface. The preceding formulae are used by WinSCANOPY to compute direct radiation above the canopy for the selected sun track, which is created automatically by WinSCANOPY for a specified period of time. These calculations are a function of latitude and longitude, and the defined growing season and time zone.

PAR under the canopy was calculated the following manner: For all sun positions on a sun track the instantaneous radiation value below canopy varies between zero and the direct radiation value above canopy as a function of the pixels' value in the image under the sun tracks at the moment. When the pixel is classified as shade it is assumed that all radiation is intercepted so the value below the canopy is zero. When the pixel is classified as sky, it is assumed that all radiation above canopy passes unimpeded so it is equal to the radiation level above the canopy. These parameters include the average direct and diffuse photosyntetically active flux density over (PPFDO) and under (PPFDU) the shade tree canopy measured in μmol m^{-2} s^{-1}.

Farm management characterization

An extended version of the questionnaires used for the exploratory studies was designed to capture the details described in the previous paragraphs. All the data were subsequently digitized and managed in CInfo.

3.2.3 Quality data generation

Sample collection and processing

All sample sites were identified by the latitude, longitude, and elevation in the centre of each MU using for the case control study a Trimble ProXR GPS device with OmniSTAR real-time correction and for the exploratory study the same unit or a Garmin Etrex GPS, which is less accurate than the ProXR. Its accuracy is in a 10-20 m range, which is enough considering that the coordinates were taken in the centre of the MU and their area always had a radius, measured form the centre, superior than 30m; so that the coordinates would always fall somewhere in the area of the field.

Twelve kg of ripe berries were harvested by hand during the peak of the 2006 harvest, guided by a maturation index (Marín et al., 2003). In the estate farms, berries from 50 trees for each management practice and each biophysical variable were harvested by estate workers. For comparison, berries also were harvested from 25 control trees for each different bio-physical variable that were not subjected to fruit thinning and harvest at various canopy levels.

Samples in the small farms in Colombia were harvested by the farmers from trees in a previously delimitated 30 m x 30 m area within the identified MU. Before processing, damaged, green and infected berries as well as stones, leaves and other artifacts were removed. Immediately after harvest, samples from both the estates and the small farms were delivered to a mobile, truck-mounted processing unit. In the unit the berries were de-pulped and the mucilage removed using a J.M. Estrada Model 100 unit. The beans were subsequently fermented in 10 l buckets using only the water attached to the grains.

The samples were then dried using the integrated dryer of the processing unit. The dryer consists of a metal closet with four shelves each containing four individual drawers, which are perforated on the bottom. The dryer thus has the capacity to process 24 samples of 1-1.5 kg at the same time. Air, heated to 45°C by a gas burner, is blown into the bottom of the closet and ascends through the closet drying the beans. The most recent samples are placed in the top drawers and moved down to the next lower level when new samples were added, thereby emulating the process of industrial dryers. Samples were dried until the parchment beans reach a humidity of 10% to 12 %, which occurs normally after 14 to 16 hours. The samples were then placed in sealed plastic bags and stored at 18°C until the cupping process.

Samples from Mexico and Honduras were harvested during the peak of the 2005/06 harvest. The samples from Mexico were processed the same day according to the wet local method which included de-pulping, fermentation, washing, and drying in a standardized manual manner. The samples from Honduras were processed by the farmers. The slightly different procedures used in Honduras, Mexico and Colombia did not present a problem in the data analyses because there is no direct comparison of samples between the three countries.

Physical and sensorial evaluation

The parchment beans were milled and the percentage and weight of bean and husks determined. The density of the beans was calculated after humidity was measured. Thereafter beans with primary and secondary defects were quantified, and their weight and percentage recorded. Any beans with defects were then removed by hand. The defect-free beans were sieved and the bean size distribution determined using standard sieves from 14/64 inch to 18/64 inch. Physical assessment data were recorded but not used in the analyses presented here due to the focus on intrinsic quality.

All the samples 250 g of beans were roasted in a laboratory roaster the day before the beverage assessment. All samples were roasted at an initial temperature of 200 °C to a standard reddish-yellow color, which took about 11 minutes; the exact roasting time was recorded. Roasted beans were ground to the recommended intermediate particle size immediately before the beverage quality assessment using a precision grinder.

Sensory beverage quality assessment was done by cupping of the coffee liquid prepared for each sample: water (150 ml at 97 °C) was poured on 10 g of ground coffee in each of five cups. This produces coffee with a range of 1.1% to 1.3% soluble solids. The five cups were treated as replicates for the sensory beverage quality assessment. The sensory attributes evaluated were fragrance, aroma, acidity, aftertaste, body, flavor, sweetness, preference and final score.

- Fragrance is the sensation of gases released from ground coffee;
- Aroma is the sensation of gases released from brewed coffee. Fragrance and aroma were assigned one value;
- Acidity is a measure of the intensity of acidic sensation;
- Aftertaste is the taste that remains in the mouth after having tasted the brewed coffee;
- Body is the oral feeling of viscosity;
- Flavor is the taste perception of the coffee beverage on the tongue;
- Sweetness is the detection of soluble sugars on the tip of the tongue;
- Preference represents the overall impression of the coffee by the cupper; and
- Final score is the sum of the attributes evaluated plus three times their average.

The attributes were rated on a scale of 1 to 10 with 0.5 point increments, using the jointly with cuppers adapted cupping protocol of the Specialty Coffee Association of America (Lingle, 2001). A score of one implies a beverage with many defects, two some defects, three a very deficient beverage, four a deficient beverage, five is a standard coffee, six is a good coffee, seven is very good, eight is an excellent coffee, and nine is a coffee of exceptional quality. For the analyses, final score values were used because they are a summary indicator of all attributes. Final score values range from 0 to 80 because they are the sum of ten single attributes.

The Colombian samples were cupped by one cupper with a high international reputation. Only the samples of the case control experiment in Inzá were assessed by a national panel of several cuppers of which only the results of the most consistent cupper were included in the analyses. The repetition samples for the assessment of the consistency of the cupper were cupped by a panel also. The Honduran samples were cupped by a national panel of 16 cuppers in the IHCAFE cupping laboratory in San Pedro Sula according to the SCAA protocol. The Mexico samples were assessed by a panel of seven cuppers in the cupping laboratory of Café-Veracruz, A.C. also according to SCAA standards. They followed the official Mexican norm of assessing only the attributes fragrance, aroma, aftertaste, acidity and body. Mexican cuppers used a scale that ranges from 0-15, 0-5 being low quality, 5-9 medium quality and >9 high quality. The different scales used and experts used for the data sets did not present a problem in the statistical analyses because there is no direct comparison between samples from the three countries.

3.3 Analytical Methods

The analytical methods are divided in point statistics and prediction models.

3.3.1 Point statistics

Descriptive statistics

Summary statistics were computed for the all the data. Various multivariate analyses, including cluster analyses, principle component analyses and discriminate analysis were applied as described below. For comparison of treatments ANOVA and correlations analyses were applied (Hair et al., 1992).

Note on data scale

All the production data and the sensorial data on product quality used in this study were measured on an interval or ratio scale. However, information of sensorial quality was measured on a quasi-interval scale, that is product qualifications were made on a scale of 0 to 10 with increments of 0.5 giving a range of 21 points available. While such data are now commonly used in similar studies (Avelino et al., 2005; Decazy et al., 2003; Vaast et al., 2006), some may question the validity of using these data in parametric statistical methods. The sensorial data described here are analogous to a Likert scale (completely agree, strongly agree, agree, etc.), which are commonly analyzed using interval procedures. In considering ordinal Likert scale items, in a review of the literature Jaccard and Wan (Jaccard and Wan, 1996) conclude, “for many statistical tests, rather severe departures (from intervalness) do not seem to affect Type I and Type II errors dramatically.” Therefore, provided the scale item has at least five, and preferably seven categories, the assumption of normal distribution, required for many tests, may be assumed to be valid. Conversely, as the number of points decreases, it will be more likely that the distribution departs from the assumption of normality. The 21 points used here provides a considerable safety margin.

Correlation and regression, and test for significance

ANOVA analyses and pearson correlation and regression were conducted using the S+ package (Insightful, 2001).

Kappa statistic

The accuracy of the output of the different modeling techniques was calculated with the Kappa statistic (Cohen, 1960; Congalton, 1991). The Kappa statistic assesses the extent to which models predict occurrence at a rate higher than expected by chance

(Monserud and Leemans, 1992). The results vary from 1.0 for perfect prediction down to 0.0 when agreement occurs only due to chance. The performance of the model was summarized in an error matrix that cross tabulates the observed and the predicted presence/absence pattern (Fielding and Bell, 1997) and based on the values in this matrix the Kappa statistic was calculated. Since the Kappa statistic is asymptotically normally distributed, a basic z-score can be used for significance testing, based on the associated p value (Congalton and Green, 1999). The calculations were made in Cohen`s Kappa Classification Table Metrics 2.0 extension of ArcView (Jenness and Wynne, 2005). The Kappa statistic can also be used to give a qualitative assessment of the extent to which the model predicts rates higher than by chance: 0 = no agreement, 0.0-0.19 poor agreement, 0.20-0.39 fair agreement, 0.4-0.59 moderate agreement, 0.60-0.79 substantial agreement, 0.80-1.00 almost perfect agreement.

For differences in model performance the MacNemar test was applied, which can cope with dependent test samples and its use is recommended when comparing the performance of alternative modeling techniques (De Leeuw et al., 2006).

ROC and AUC

The ROC is a threshold-independent technique. A ROC plot is obtained by plotting the fraction of correctly classified cases on the y axis (sensitivity) against the fraction of wrongly classified cases (1-specificity) for all possible thresholds on the x axis (Fielding and Bell, 1997). The area under the ROC function curve (AUC) is taken as a measure of overall accuracy that is not dependent upon a particular threshold.(Deleo, 1993). The values of the AUC vary from 0.5 (no apparent accuracy) to 1 (perfect accuracy). The ROC Plotting and AUC Calculation Transferability Test 1.3 software (Schröder, 2004), was used to calculate the AUC. The AUC value estimates if the prediction is significantly different as opposed to chance differences: AUC = 0.5: no discrimination; 0.6 <AUC> 0.7: moderate discrimination; 0.7< AUC > 0.8: acceptable discrimination; 0.8< AUC> 0.9: excellent; AUC> 0.9: outstanding.

Cluster analyses

The purpose of cluster analysis is to place objects into groups or clusters suggested by the data, not defined *a priori*, such that objects in a given cluster tend to be similar to each other in some sense, and objects in different clusters tend to be dissimilar. Each observation begins in a cluster by itself. The two closest clusters are merged to form a new cluster that replaces the two old clusters. Merging of the two closest clusters is repeated until only one cluster is left.

The data representations of objects to be clustered also take many forms. The most common are:

- A square distance or similarity matrix, in which both rows and columns correspond to the objects to be clustered. A correlation matrix is an example of a similarity matrix.
- A coordinate matrix, in which the rows are observations and the columns are variables. The observations, the variables, or both may be clustered.

Any generalization about cluster analysis must be vague because a vast number of clustering methods have been developed in several different fields, with different definitions of clusters and similarity among objects.

The various clustering methods differ in how the distance between two clusters is computed. I used Ward's minimum-variance method where the distance between two clusters is the ANOVA sum of squares between the two clusters summed over all the variables. At each generation, the within-cluster sum of squares is minimized over all partitions obtainable by merging two clusters from the previous generation. The sums of squares are easier to interpret when they are divided by the total sum of squares to give proportions of variance (termed squared semi-partial correlations).

Discriminant analyses

The purpose of discriminant analysis is to find a mathematical rule, or *discriminant function*, for determining to which class an observation belongs, that is to say, discriminant analysis is used to classify observations into two or more known groups on the basis of one or more quantitative variables.

Classification can be done by either a parametric or a nonparametric method. A parametric method is appropriate only for distributions that are approximately normal within each class. The method generates either a linear discriminant function (the within-class covariance matrices are assumed to be equal) or a quadratic discriminant function (the within-class covariance matrices are assumed to be unequal).

When the distribution within each group is not assumed to have any specific distribution or is assumed to have a distribution different from the multivariate normal distribution, nonparametric methods can be used to derive classification criteria.
The performance of a discriminant function can be evaluated by estimating error rates (probabilities of misclassification). Error count estimates and posterior probability error rate estimates are evaluated. The error rates are also estimated by cross validation. The linear discriminant function used here is:

$$\text{Constant} = -0.5\overline{X_j}' \, COV^{-1} \, \overline{X_j} \qquad \text{Coefficient Vector} = COV^{-1} \, \overline{X_j} \tag{7}$$

3.3.2 Prediction models

Bayesian probability (CaNaSTA)

Various modeling approaches exist to identify suitable niches for specific crops, and one such approach has been used to create a spatial decision support (SDS) tool, that is, a software tool based on geographical information science, which can assist users in decision-making. The CaNaSTA algorithm (O'Brien, 2004) creates conditional probability tables of all predictor variables against response variable categories. In the case of coffee, predictor variables include climate and topographic factors and the response variables include sensorial, physical or biochemical quality attributes. The primary model output is a discrete probability distribution at each location. A certainty value is also associated with each location, derived from the number of occurrences in the trial data of a particular combination of predictors and responses.
The probability distribution consists of the probability that the response variable is in each potential state. This information can be used to create maps showing the most likely response value (‘Most likely’). The values in the probability distribution can also be weighted to produce a suitability value (‘Score’). Finally, the certainty value can also be displayed as a map (‘Certainty’), and can assist in the interpretation of the results. Once locations have been identified where a particular response is likely, further analysis can be carried out to determine which predictor variables are important. These driving factors can be either positive or negative, and can help with the analysis of specific conditions required for specialty coffee.

Calculating posterior probability distribution

A 'prior probability' is an initial estimate that may be modified once more information becomes available. If *Y* is a response variable, then the prior probability of *Y* is denoted *P*(*Y*). 'Joint probability' refers to the probability of two events occurring together, such as a species thriving in a location with certain biophysical conditions. This is denoted by *P*(*X*, *Y*), where *X* is a predictor variable (e.g., "rainfall is low") and *Y* is a response variable (e.g., "quality is high"). 'Conditional probability' is the probability of a response variable being in a given state, given that a predictor variable is a particular state, and is denoted *P*(*Y* | *X*).

Conditional probability can be calculated from prior and joint probability:

$$P(Y \mid X) = \frac{P(Y, X)}{P(X)} \tag{8}$$

It can be shown that posterior probability can be calculated from conditional and prior probabilities:

$$P(Y \mid X^1, X^2, ..., X^n) \propto P(Y) \prod_k \left(\frac{P(Y \mid X^k)}{P(Y)} \right) \tag{9}$$

where X^k is the k^{th} predictor variable ($k = 1 \dots n$).

For simplicity the left-hand side of equation 5, the posterior probability distribution $P(Y \mid X^1, X^2, \dots, X^n)$ can be written as $(y_1, y_2, \dots, y_m)$, $\Sigma y_j = 1$, where y_j is the probability that the response variable *y* will be in class *j*.

Score

The score metric is a weighted average of $y_1, y_2, \dots, y_m$, devised as a way of displaying a summary of the entire probability distribution in one map. The assumption is that the classes are ordinal, and class *j* is ranked higher than class $j - 1$ ($2 \le j \le m$).

The score *s* is calculated as follows:

$$w_i = \frac{i-1}{n-1} \qquad s = \sum w_i y_i \tag{10}$$

where *n* is the total number of response classes, w_i is the weight for the i^{th} class and y_i is the posterior probability value of the i^{th} class.

For example, for a response variable with four categories and probability distribution (0.2, 0.4, 0.3, 0.1), score s = 0*0.2 + 1/3*0.4 + 2/3*0.3 +1*0.1 = 0.433.

Certainty

Each conditional probability distribution is assigned a certainty value of ‘low’, ‘medium’ or ‘high’. When calculating posterior probability, these are assigned the values 0, 1 and 2 respectively, and are simply averaged over predictor variables to produce a combined certainty value. In general, if there are few data points in the input data in a given predictor variable class, certainty for all locations falling in this class will be low.

Driving factors

Once a probability surface has been created, it can be further analyzed to identify driving factors. Analysis of driving factors attempts to identify the variable classes that disproportionately contribute to high values in the probability surface (positive driving factors) and low values in the probability surface (negative driving factors).

A sample of size n is taken from a region of interest and is sorted by response value so that three sets can be obtained:

N = the set of all elements in the sample (size n);

$Q1$ = the set of elements in the upper quartile, ranked on response (size $n(Q1) = n/4$); and

$Q4$ = the set of elements in the lower quartile, ranked on response (size $n(Q4) = n/4$).

For each predictor variable, the following can be calculated:

$n(x_i)$ = the number of elements in N that are in category i for predictor variable x;

$n(x_i, Q1)$ = the number of elements in $Q1$ that are in category i for predictor variable x; and

$n(x_i, Q4)$ = the number of elements in $Q4$ that are in category i for predictor variable x.

Then category i for predictor variable x is considered a positive driving factor if:

$$\frac{n(x_i, Q1)}{n(Q1)} \Big/ \frac{n(x_i)}{n} \geq c \qquad (11)$$

and is considered a negative driving factor if:

$$\frac{n(x_i, Q4)}{n(Q4)} \Big/ \frac{n(x_i)}{n} \geq c \qquad (12)$$

where c (> 1) is a user-defined threshold, with default value of 2.0.
Although the default is upper quartile and lower quartile (25%), this value can also be user-defined. For example, if there are n = 100 locations in the sample, of which $n(x_i)$ = 20 are in predictor variable class i, and there are $n(Q1)$ = 25 locations in the upper quartile, of which $n(x_i, Q1)$ = 15 are in predictor variable class i, then the left-hand side of equation 8 evaluates to 3.75 and class i is therefore a positive driving factor.

Maximum Entropy

"Maximum entropy (MaxEnt) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent (one's) incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average (average value for a set of sample points taken from the target distribution" (Phillips et al., 2006). Similar to logistic regression, MaxEnt weights each environmental variable by a constant. The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution.

BioClim

BioClim utilizes a boxcar environmental envelope algorithm to identify locations that have environmental conditions that fall within the range over which a given element is known to occur. Specifically the minimum and maximum values for each environmental predictor are identified and used to define the multidimensional environmental box where the element is known to occur. Study area sites that have environmental conditions within the boundaries of the multidimensional box are predicted as potential sites of occupancy of the element. Since this method is known to be sensitive to outliers, often the predicted distribution is calculated by disregarding 5% of the lower and higher values for each environmental predictor variable and is termed the "core bioclimate".

Domain

The Domain algorithm calculates the Gower distance statistic between each cell on the map and each point, using the values of the climate variables. The distance between point A and cell B for a single climate variable is calculated as the absolute difference in the values of that variable divided by the range across all points, The Gower distance is then the mean over all climate variables:

$$d_{AB} = \frac{1}{p}\sum_{k=1}^{p}\frac{|A_k - B_k|}{range(k)} \tag{13}$$

d_{AB} = Gower distance

p = Total number of climatic variables

A_k = Value of point k in point A

B_k = Value of variable k in cell B

range (k) = Range of variable k across all the points present.

The Gower similarity indicator is calculated as:

$$D = 1 - d_{AB} \tag{14}$$

The similarity between each pixel of the layer and the presence points is mapped. The higher the value of D for one pixel, the more similar are the climatic variables of this cell to the presence point data. The pixel has similar conditions to the presence data. Predictions are not to be interpreted as predictions of probability of occurrence but as a measure of classification confidence. (Carpenter et al., 1993; Hijmans et al., 2005b)

3.4 Design and outline of analyses

3.4.1 Environment quality interactions

Specific objective 1: To describe and quantify the impact of the natural environment on coffee liquor quality.

In an extensive literature review, the environmental factors that impact on the quality of coffee liquor were identified. The ten factors identified consisted of topographic and climatic variables; their values were generated for each sampling point. The variation of the environmental factors and the quality attributes within and between growing regions (environmental clusters and geographical areas) and the interactions between the quality and the environmental factors were quantified.

3.4.2 Management quality interactions

Specific objective 2: To describe and quantify the impact of agronomic management and post-harvest processes on coffee liquor quality.

In a literature review, production factors that determine quality were identified. The production factors consist of agronomic management practices and post-harvest processes. The variation of production factors within and between the study areas El Tambo-Timbio and Inza is described.

3.4.3 Spatial decision support tools

Specific objective 3: To present, compare and test spatial analyses tools for the identification of high quality coffee niches.

CaNaSTA is a spatial decision support tool, which was adapted for this research to predict coffee qualities. As a first step, CaNaSTA was compared with existing species prediction models. The Honduras data set was used for the comparison, which consisted of 637 sites sampled. Of these, two samples were removed because of incomplete quality data, 49 were removed because they were out of the coffee areas delimited by the Instituto Hondureno de Café IHCAFE, and five were eliminated because a semi-variogram analysis flagged them as outliers. This left 581 samples for the comparison.

The samples were divided in three quality classes according to their final cupping score: A less than 80 (121 samples), AA 80 to 85 (278 samples), and AAA greater than 85 (183 samples). IHCAFE cuppers score on average five points above SCAA cuppers, so these quality classes are equivalent to SCAA scores: A less than 75, AA 75 to 80 and AAA greater than 80. A coffees are below the specialty coffee range, AA coffee that have potential to become specialty coffees and AAA are true specialty coffees. For the prediction data 75% of the data were selected at random, while the remaining 25% were used as test data. The models were run for three different evidence data combinations. The first was for all ten environmental factors (annual average precipitation, annual average dry month, annual average temperature, annual average dew point, annual average diurnal temperature range, northness, eastness, elevation, slope, annual average solar radiation), the second was for the two non-topographic factors most correlated with quality (average annual dew point and annual average temperature), and the third was for elevation, the one factor most strongly correlated with quality.

CaNaSTA was then validated with a data set from Cauca of 88 sample points, 44 from sites in El Tambo-Timbio, 27 from Inzá and 17 from other municipalities. Three different tests and training sets were used with 25/75, 50/50 and 75/25 percent of the data to predict and test the model, respectively. Each set was repeated 10 times with predicting and testing sites selected at random. The final score of a SCAA quality class was the sum of ten evaluated sensorial attributes, each having a score between 1 and 10. Because the emphasis is on quality coffees, only those samples scoring in the range of 70-90 were used in the evaluation. The likelihood ratio of the dependency of the quality class on the predictor scores was tested using the chi-square test.

The test method uses a conformity matrix where the axes represent the quality classes and predictor ranges and the cells of the matrix cells show the agreement between them. “Driving factor” analysis was then applied to determine the factors that had most impact on sensorial coffee quality. The analysis was conducted on the two different environmental niches and on the entire Cauca data set. The Inzá niche covers 16,005 ha, El Tambo-Timbio 160,765 ha, and the sampled municipalities of Cauca cover 775,866 ha. Finally quality niches in Cauca were predicted and delimited and the interactions between coffee liquor quality and environmental factors determined and quantified.

3.4.4 Site-specific farm management

Specific objective 4: To develop and test concepts of site-specific farm and post-harvest management practices for improved coffee quality.

Case studies to asses the potential of site-specific farm and post-harvest management were conducted. To appraise the potential of agronomic management the study looked at biophysical and agronomic management variables. The importance of slope orientation, slope position, variety, shade, fruit thinning and harvest per canopy were assessed. To appraise the post-harvest processes, on-farm trials pair sample comparisons were conducted, which compared the quality of farmer-produced coffee and the on-farm standardized sample. The effect on coffee quality of the time lag between harvest and processing, the influence of the equipment used, the fermentation time and the drying methodology were also assessed. These evaluations gave a final appraisal of the suitability of site-specific management.

3.4.5 Qualitative quality control methods

Specific objective 5: To determine the utility of qualitative quality control methods.

Three samples of different origins in Cauca were cupped by five cuppers repeatedly. Discriminate analyses and principal component analyses (PCA) were used to assess the consistency of the cuppers, leading to conclusions about the use of quality control methods.

4 ENVIRONMENT QUALITY INTERACTIONS

Specific objective 1: To describe and quantify the impact of the natural environment on coffee liquor quality.

The dependency of coffee-cup quality on environmental factors has been described only recently (Avelino et al., 2005; Decazy et al., 2003; Muschler, 2001; Vaast et al., 2004b). Because such studies are costly, they were usually conducted in few experimental sites. From these, the findings and generated knowledge were then scaled up and applied to wide areas without taking into account the changes in the environment over space. In contrast, geographical analyses can help to interpolate and extrapolate point data to obtain a higher coverage of information. This chapter deals with the interactions between the environment and the beverage quality of coffees using environmental data generated by means of GIS. Data sets from southern Colombia and Honduras are used to compare different growing conditions. In Southern Colombia two high quality niches (El Tambo-Timbio and Inzá) and in Honduras five distinct environments, selected according to an environmental cluster analysis, were used as study areas. This chapter starts with a literature review on the impact of environmental factors on beverage quality, followed by a quantification of the variability of environmental factors and quality in space. The chapter concludes with the quantification of the variable impact of environmental factors on coffee beverage quality.

4.1 Impact of the environment on sensorial quality

4.1.1 Topography

Topography refers to the physiographic characteristics of land in terms of elevation, aspect and slope. Elevation is the factor cited most as the determinant of coffee quality in general and specifically of coffee beverage quality. It is generally accepted that coffees grown at higher altitudes are higher quality (Avelino et al., 2002; Avelino et al., 2005; Boot, 2001; Buenaventura-Serrano and Castaño-Castrillón, 2002; Bureau, 2002; Decazy et al., 2003; Griffin, 2001; Ibarra, 1986; Pochet, 1990; Sylvain, 1965; Vaast et al., 2004a). The elevations cited differ depending on the growing regions; authors also differentiate between altitudes suitable for growing coffee and the optimal altitudes for coffee beverage quality (Table 7). Aspect as defined here is the compass direction that sloping land faces. Avelino et al. (2005) found that east-facing slopes produce beverage qualities with generally superior scores, higher in acidity and preferred by cuppers.

Table 7: Elevation ranges apt for coffee production

	Elevation (masl)	Region /Country	Reference
Growing conditions	1000 to 1800	Western Ecuador	(Cofenac, 2003)
	300 to 1 500	Northwest of Pichincha (Ecuador)	(Cofenac, 2003)
	> 500	Manabi (Ecuador)	(Cofenac, 2003)
	1400 to 2000	East Africa	(Naylor, 1990)
	450 to 1500	Zimbabwe	(Naylor, 1990)
	1400 to 2100	General statement	(Njoka and Mochoge, 1997)
	600 to 1500 / max 2000	General statement	(Vitzthum, 1976)
	400 to 2000	General statement	(Fischersworring and Robkamp, 2001)
	1300 to 1700	Colombia	(Cenicafe, 1970)
High quality conditions	800 – 1000 regular quality > 1200 good quality	Central America	(Bureau, 2002)
	>1370, more high quality coffees than in lower altitudes	General statement	(Foote, 1963)
	> 1000 most appreciated coffees	Honduras	(Decazy et al., 2003)
	1450, 1550, and 1650	Colombia (ecotype 206B)	(Buenaventura-Serrano and Castaño-Castrillón, 2002)
	>1115, best coffees in high elevation	Honduras	(Avelino et al., 2002)
	1200 to 2000, depending on latitude	General statement	(Fischersworring and Robkamp, 2001)

4.1.2 Climate

Climate is the conditions of the atmosphere near the earth's surface averaged over a long period of time, usually a minimum of thirty years. Meteorological variables used to describe climate are most often surface variables such as temperature, rainfall, barometric pressure, wind strength and direction. Important variables for coffee quality, however, are rainfall, temperature, humidity and solar radiation. Climate influences coffee quality through three functional aspects, fruit development, fermentation and incidence of defective grains (Cortez, 1997). Annual rainfall is the most often quoted factor; there are many references in the literature to growing conditions but only few on the specific conditions for high quality coffee. Annual rainfall where coffee is grown varies according to the region, ranging from 600 mm in Zimbabwe (Naylor, 1990) to 4000 mm in Ecuador (Cofenac, 2003). Rainfall where high quality is grown varies less, ranging from 1000 mm (Njoka and Mochoge, 1997) to a little over 1700 mm (Avelino et al., 2002) (Table 8).

Table 8: Precipitation ranges apt for coffee production

	Precipitation (masl)	Regions /Country	Reference
Growing conditions	1500 to 2500	General statement	(Mitchell H.W., 1988)
	600 to 1200 (single rainy season of 4 months)	Zimbabwe	(Naylor, 1990)
	1200 to 1800 mm (two rainy seasons)	Ethiopia, Congo, Colombia, Brazil	(Sylvain, 1965)
	1000 to 4000	Ecuador	(Sylvain, 1965)
	1000 to 3500	General statement	(Fischersworring and Robkamp, 2001; Trojer, 1968)
	1800 to 2800	Colombia	(Cenicafe, 1970)
	> 230 rain days per year	Colombia	(Cenicafe, 1970)
	1800 to 2800	Colombia	(Cenicafé, 1979)
	Min.760 to 1780, max. 990 to 3000	Ecuador	(Cofenac, 2003)
	1800 to 2800	Colombia	(Suárez, 1972)
	1600 to 1800	General statement	(Guharay et al., 2000)
	1200 to 1800	General statement	(Enríquez, 1993)
	> 1778	General statement	(Haarer, 1984)
High quality conditions	From 1000 to 1150	General statement	(Njoka and Mochoge, 1997)
	Less than 1600	Honduras	(Decazy et al., 2003)
	Average 1726	Honduras	(Avelino et al., 2002)

Apart from total annual rainfall, its distribution is also important. Ibarra (1986) states that in Honduras best coffee is produced where the wet seasons are as long as nine months. Other authors recommend a dry season of no more than 3 or 4 months (Table 9).

Alsoof rainfall distribution during berry development is crucial, since it directly influences harvest quality (Suarez, 1979). Venkataramanan (2003) states that inadequate rainfall during berry development causes water stress in the plants and results in physical defects of the beans. In particular, inadequate rainfall during the stage of rapid swelling of the berries (42-102 days after flowering) and first endosperm filling stage (117-152 days) can affect normal berry development and may result in small beans and a lower percentage of best quality beans (Venkataramanan, 2003).

Table 9: Number of dry month apt for coffee production

	Dry month (# month)	Regions /Country	Reference
Growing conditions	3 (coinciding with harvest)	General statement	(Mitchell H.W., 1988)
	3	Ecuador	(Cofenac, 2003)
	2 to 3	General statement	(Guharay et al., 2000)
High quality conditions	< 4	General statement	(Njoka and Mochoge, 1997)
	3	Honduras	(Ibarra, 1986)

Annual average temperature is also an important factor in coffee quality (Table 10). Authors also quote the diurnal temperature range to have strong influence on coffee quality (Illy, 2001). Griffin (2001) states that a greater diurnal range promotes the production of sugars in fruits in general. Consequently, large diurnal ranges in temperature may increase the sweetness of a coffee. Njoka and Mochoge (1997) state that Arabica coffee requires temperatures ranging from a daily maximum of 32ºC to a minimum of 7ºC. The minimum diurnal range should be about 19ºC.

Table 10: Average annual temperature ranges apt for coffee production

	Annual average temperature (°C)	Regions /Country	Reference
Growing conditions	20, oscillating from 18 to 21	Ethiopia, Congo, Colombia, Brazil	(Sylvain, 1965)
	18 to 24	Ecuador	(Sylvain, 1965)
	18.5 to 21	Colombia	(Cenicafe, 1970)
	15 to 25	General statement	(Vitzthum, 1976)
	19 to 21.5	Colombia	(Cenicafé, 1979)
	18 to 21	General statement	(Enríquez, 1993)
	19 to 21	General statement	(Fischersworring and Robkamp, 2001; Haarer, 1984)
	17 to 23	General statement	(Guharay et al., 2000)
	18 to 24	General statement	(Cofenac, 2003)

Exposure to sunlight also impacts coffee quality (Barel and Jacquet, 1994; Cofenac, 2003) and growers manage shade to enhance quality. COFENCA (2003) recommends managing shade to achieve sun exposure greater than 1000 hours per year.

Relative humidity has influence on coffee quality (Tale 11). References in the literature recommend 70 to 95 % of relative humidity to obtain high quality coffee.

Table 11: Relative humidity for coffee production

	Relative humidity (%)	Regions /Country	Reference
Growing conditions	70 to 80	Ethiopia, Congo, Colombia, Brazil	(Sylvain, 1965)
	70 to 95	General statement	(Enríquez, 1993; Fischersworring and Robkamp, 2001)
	> 92 cause favorable conditions for disease	General statement	(Cofenac, 2003)

Soils indicators will be discussed in chapter DII and EII because the resolution of the data at a field level is higher than the GIS-generated values.

Based on the literature review the following ten environmental factors were deemed as decisive for coffee beverage quality and subsequently generated by means of GIS: Average annual precipitation, average annual temperature, average annual dew point, and average annual diurnal temperature range, average annual number of dry month, solar radiation, slope, eastness, northness, and elevation. Dew point was used as a proxy for relative humidity, and eastness and northness as more meaningful measures of aspect.

4.2 Quantification of the variability in space

4.2.1 Variability of environmental factors

Environmental factors are highly variable in space. Table 12 and 13 display the summary statistics of the ten variables for Honduras and Cauca and for their sub zones, in Cauca these are the two high value niches El Tambo-Timbio and in Honduras the five clusters described above.

Table 12: Descriptive statistic of sampled sites in Honduras

		P	T	DP	DTR	DM	SR	S	E	N	EL
All data (582)	MIN	1053	17.3	10.1	9.0	3	15.0	0.0	-1.0	-1.0	402
	MEAN	1543	20.5	12.6	11.3	5.3	22.1	13.3	-0.4	0.2	1147
	MAX	2181	24.5	18.2	12.5	6	25.0	37.5	1.0	1.0	1677
	STDW	193	1.3	1.6	0.7	0.8	1.4	6.7	0.7	0.7	244
Clust. 2 (80)	MIN	1453	19.8	11.8	9	3	19.0	2.0	-1.0	-1.0	402
	MEAN	1818	22.0	15.5	10.7	4	22.8	13.4	0.0	0.2	855
	MAX	2181	24.5	18.2	12.3	6	25.0	31.6	1.0	1.0	1262
	STDW	182	1.6	1.2	0.9	0.7	1.6	7.2	0.7	0.7	194
Clust. 3 (36)	MIN	1463	17.3	10.1	11.5	5	22.0	1.8	-1.0	-1.0	1330
	MEAN	1613	18.3	11.2	12	5.9	23.6	12.2	0.4	-0.1	1508
	MAX	1765	19.5	12.1	12.4	6	25.0	24.0	0.9	1.0	1677
	STDW	70	0.6	0.5	0.2	0.2	0.9	5.6	0.6	0.7	90
Clust. 4 (192)	MIN	1200	17.9	11.0	9.3	4	18.0	1.2	-1.0	-1.0	936
	MEAN	1545	19.6	12.6	11.5	5.4	23.3	13.2	0.0	-0.6	1306
	MAX	1954	21.6	15.7	12.4	6	25.0	37.5	1.0	1.0	1609
	STDW	135	0.7	0.8	0.5	0.7	1.3	6.6	0.7	0.7	132
Clust. 5 (150)	MIN	1053	19.5	12.4	10.1	4	20.0	1.0	-1.0	-1.0	500
	MEAN	1408	21.3	14.5	11.3	5.5	23.3	11.7	0.1	0.2	1007
	MAX	1672	24.2	17.4	12.5	6	25.0	25.6	1.0	1.0	1330
	STDW	146	10.3	1.2	0.5	0.6	1.1	6.1	0.7	0.7	180
Clust. 7 (115)	MIN	1095	18.4	11.1	10.2	4	19.0	0.0	-1.0	-1.0	675
	MEAN	1486	20.4	13.4	11.4	5.5	22.5	14.9	-0.2	0.4	1161
	MAX	1753	24.0	17.4	12.4	6	25.0	32	1.0	1.0	1547
	STDW	139	1.0	1.2	0.5	0.6	0.6	6.7	0.6	0.6	173

P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°), N = northness (cos(aspect*pi)/180)), E = eastness (sin(aspect*pi)/180)), and EL = elevation (masl).

Table 13: Descriptive statistic of sampled sites in Cauca, Colombia

		P	T	DP	DTR	DM	SR	S	E	N	EL
All data (88)	MIN	1587	16.6	10.9	10.5	0	21.0	2	-1.0	-1.0	1434
	MEAN	2108	18.3	12.4	10.9	1.6	24.6	10.6	0.2	0.0	1750
	MAX	2628	20.9	14.8	11.4	3	25.0	41	1.0	1.0	2001
	STDW	313	0.8	0.6	0.2	0.7	0.7	7.9	0.7	0.7	108
Inzá (27)	MIN	1587	16.6	10.9	10.5	0	23	9	0.2	-1.0	1700
	MEAN	1665	17.7	12.0	10.6	0.7	24	13.5	0.7	0.4	1843
	MAX	1761	18.8	13.0	10.7	1	27	29	1.0	0.8	2001
	STDW	50	0.6	0.6	0.05	0.5	0.0	4.8	0.2	0.5	85
El Tambo-Timbio (48)	MIN	1978	17.6	11.7	10.9	2	21.0	2	-1.0	-1.0	1434
	MEAN	2339	18.4	12.4	11.0	2.0	24.8	8.3	-0.0	0.2	1727
	MAX	2628	20.9	14.8	11.2	3	25.0	41	1.0	1.0	1871
	STDW	109	0.6	0.5	0.06	0.1	0.7	7.8	0.7	0.7	82

P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°), N = northness (cos(aspect*pi)/180)), E = eastness (sin(aspect*pi)/180)), and EL = elevation (masl).

In Cauca, coffee is generally grown in higher altitudes (1750 masl) than in Honduras (1150 masl); the variables related to altitude, such as average annual temperature, average annual dew point, and average annual diurnal temperature range are lower in Cauca than in Honduras by 2.2 °C, 0.2°C, and 0.4°C respectively. Average annual precipitation is higher in Cauca (2110 mm) than in Honduras (1540 mm), and dry month are fewer in Cauca than in Honduras. Solar radiation is also higher in Cauca (24.6 $MJm^{-2}d^{-1}$) than in Honduras (22.1 $MJ\ m^{-2}d^{-1}$). Average growing altitude varies in Honduras between clusters from 860 masl to 1510 masl, and accordingly the differences in average annual temperature, average annual dew point, and average annual diurnal temperature range are of 4.3 °C, 4.3°, and 0.3°C. Average annual precipitation differs between clusters by 410 mm and average annual dry month by 1.9 month/year and solar radiation by 1.1 $MJ\ m^{-2}d^{-1}$. In Cauca the difference in elevation between the two niches is of 116 m, and accordingly the differences in average annual temperature, average annual dew point, and average annual diurnal temperature range are 0.7°C, 0.4°C, and 0.4°C. The differences in solar radiation are 0.8 $MJ\ m^{-2}d^{-1}$. The variability of the environmental factors is higher within the Honduran clusters than between Honduras and Cauca or within the Cauca niches. This is indicated by larger ranges and bigger standard deviations.

In Honduras the dependency of altitude and its related temperature variables is nicely represented when mapping the factors (Figure 10). Annual average temperature, average annual dew point, and average annual diurnal temperature range show patterns very similar to elevation. Average annual dry months is represented in a north south gradient, having more dry months in the south than in the north. Annual average precipitation is linked to elevation but an east west gradient is also distinguishable, with more rainfall in the eastern zones than in the western zones. Slope, eastness and northness are linked to elevation.

Cluster analyses of the environmental factors suggest seven different environment clusters (Table 14). Less than ten sampling points fall in clusters 1 and 6, which were therefore not included in further analysis.

Table 14: Overview of number of records per cluster

Cluster	1	2	3	4	5	6	7
Records	7	80	36	192	150	3	115

In Cauca, as in Honduras, average annual temperature, average annual dew point, and average annual diurnal temperature range follow the pattern of elevation (Figure 11). Annual average precipitation shows a west-east gradient, the western zones receiving more precipitation than the eastern zones. The average annual dry month pattern follows mainly the elevation pattern. Higher altitudes receive more solar radiation than lower altitudes.

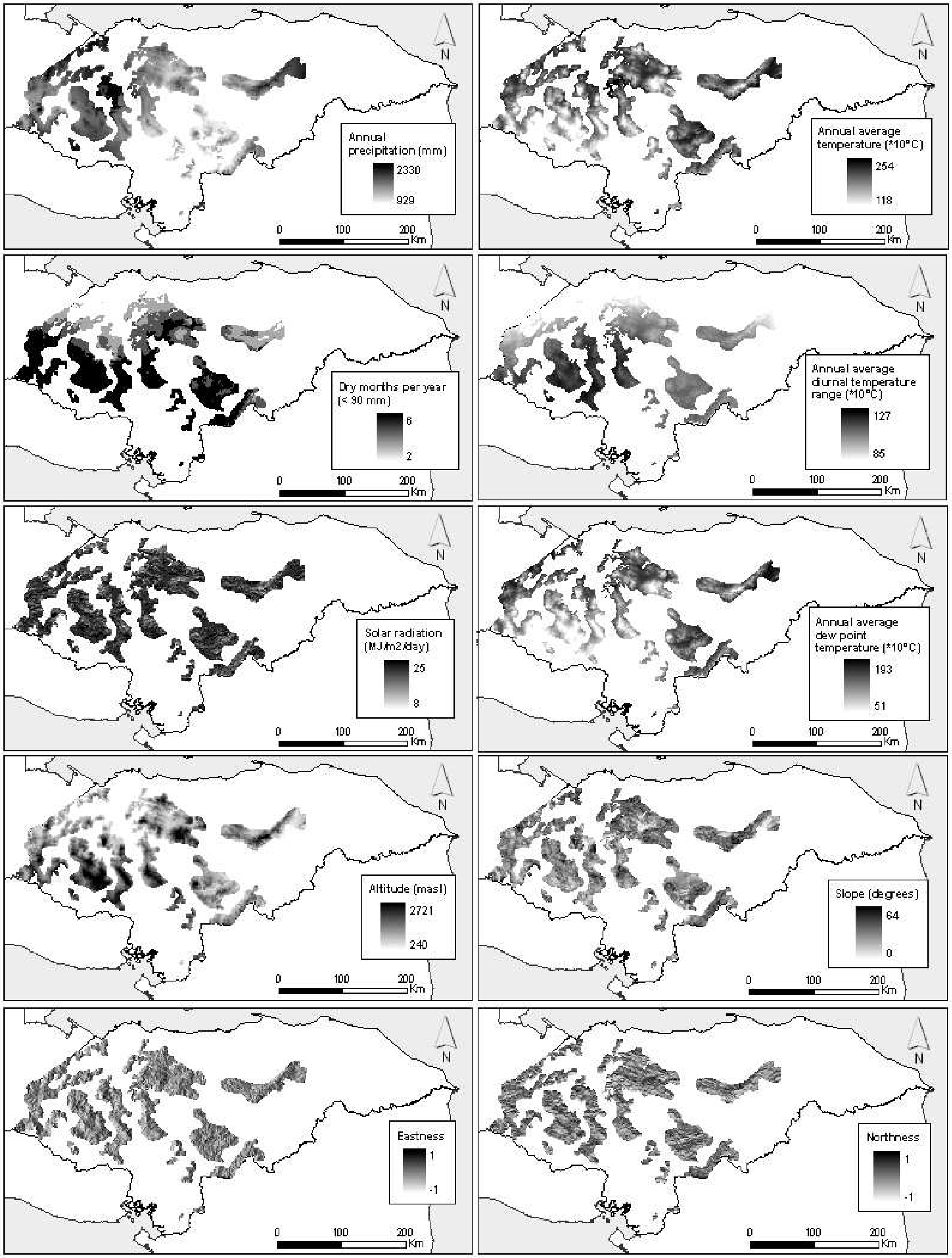


Figure 10: Variability of environmental factors in Honduras.

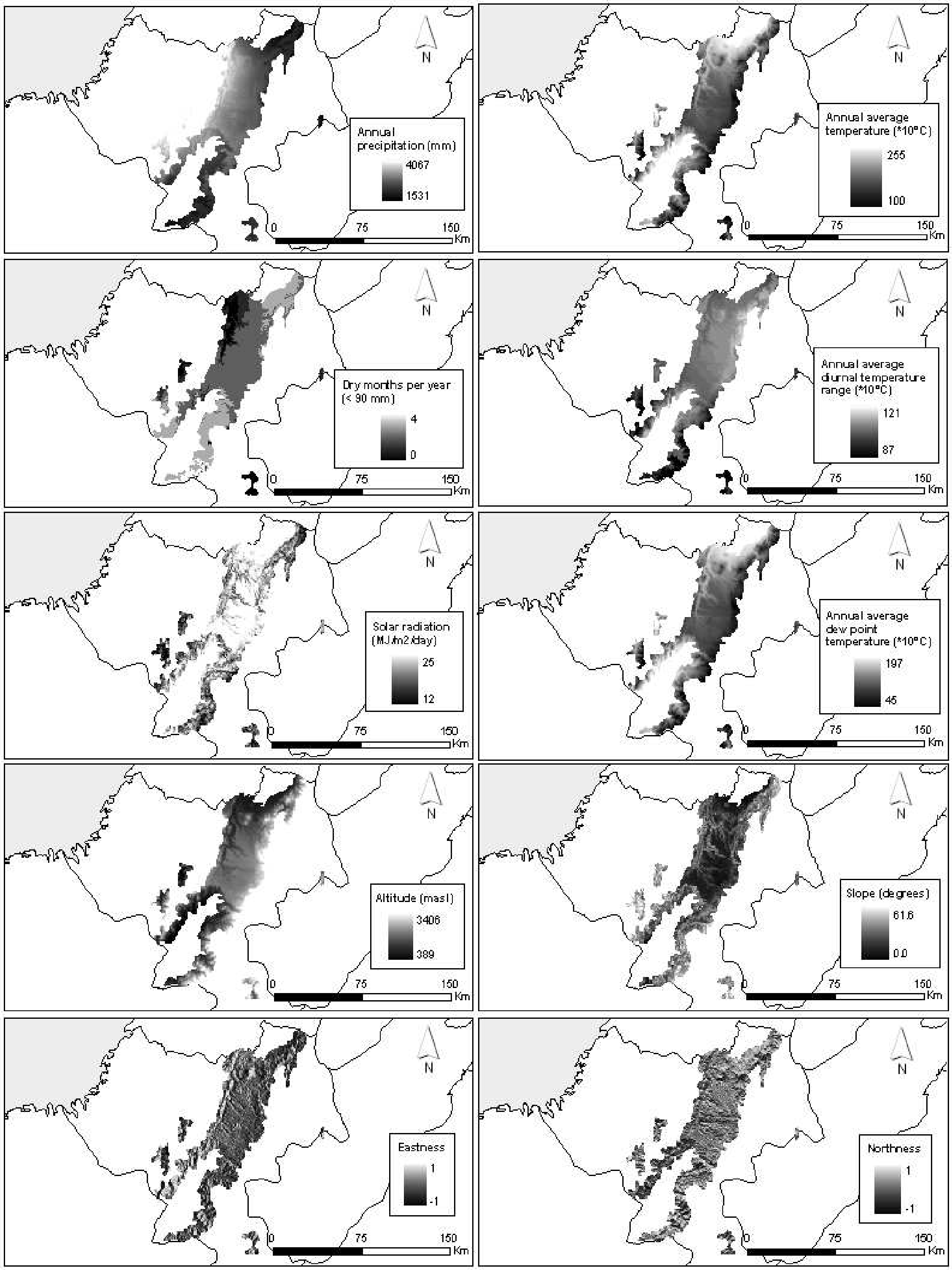


Figure 11: Variability of environmental factors in Cauca.

4.2.2 Variability of sensorial quality

Quality scores in Honduras and its individual clusters are higher than quality scores in Cauca (Table 15 and 16) . The cuppers from Honduras confirmed that on average they cup five points above the SCAA scores. The quality in Honduras and in its sub-regions is more variable than in Cauca, as indicated by the larger ranges and standard deviations. The sub-regions in Honduras were chosen on statistical bases as having similar environments. In contrast, the Cauca sub-regions were chosen on geographical bases as areas producing high-quality coffee.

Table 15: Descriptive statistic of quality in Honduras

SA & S#[1]	STATS	AROMA / F	ACIDITY	A.TASTE	BODY	FLAVOR	FINAL SCORE
All data (582)	MIN	4.4	3.8	4.0	3.9	3.7	50.0
	MEAN	6.8	6.5	6.4	6.5	6.5	82.7
	MAX	8.8	8.5	8.4	8.0	8.6	93.3
	STDW	0.6	0.7	0.7	0.6	0.7	3.6
Clust. 2 (80)	MIN	4.4	3.8	4.0	3.9	3.7	69.8
	MEAN	6.4	6.1	6.0	6.2	6.1	80.8
	MAX	7.9	8.0	8.0	7.9	8.1	90.7
	STDW	0.5	0.6	0.7	0.5	0.7	3.1
Clust. 3 (36)	MIN	5.8	5.3	5.1	5.8	5.4	77.5
	MEAN	6.9	7.0	7.0	6.9	7.0	85.3
	MAX	7.6	7.9	8.1	7.6	8.0	89.6
	STDW	0.5	0.6	0.7	0.5	0.7	3.2
Clust. 4 (192)	MIN	5.6	5.2	5.2	5.4	5.1	77.0
	MEAN	6.8	6.8	6.7	6.7	6.8	84.1
	MAX	8.3	8.5	8.4	8.0	8.6	93.3
	STDW	0.5	0.6	0.6	4.4	0.6	2.9
Clust. 5 (150)	MIN	4.9	4.6	4.5	4.7	4.6	73.1
	MEAN	6.4	6.2	6.1	6.3	6.2	81.4
	MAX	8.2	7.8	8.0	7.7	8.1	90.6
	STDW	0.5	0.6	0.6	0.5	0.7	3.1
Clust. 7 (115)	MIN	5.2	5.0	4.7	5.2	4.8	75.0
	MEAN	6.6	6.6	6.5	6.5	6.6	83.0
	MAX	8.8	7.9	8.0	7.4	8.0	90.4
	STDW	0.5	0.6	0.6	0.4	0.6	2.9

[1] SA & S# = Study area and number of samples

Table 16: Descriptive statistic of quality in Cauca

SA & S#[1]	STATS	AROMA / F	ACIDITY	A.TASTE	BODY	FLAVOR	FINAL SCORE
All data (88)	MIN	5.0	6.0	5.0	7.0	5.0	58.0
	MEAN	7.7	7.8	7.1	7.8	7.6	79.3
	MAX	9.0	9.0	9.0	9.0	9.0	90.0
	STDW	0.8	0.7	1.0	0.5	0.97	6.2
Inzá (27)	MIN	6.0	7.0	6.0	7.0	6.0	73.0
	MEAN	7.8	7.6	7.3	7.8	7.7	80.4
	MAX	9.0	9.0	9.0	9.0	9.0	89.0
	STDW	0.8	0.6	0.7	0.5	0.7	4.0
El TT (48)	MIN	6.0	6.0	5.0	7.0	5.0	60.0
	MEAN	7.9	7.9	7.2	7.9	7.7	79.7
	MAX	9.0	9.0	9.0	9.0	9.0	90.0
	STDW	0.7	0.8	1.1	0.6	1.0	6.4

[1] SA & S# = Study area and number of samples

4.2.3 Variable impact of environmental factors

Correlation between environment and quality

In Honduras, the correlation coefficients are higher than in Cauca, they reach values up to r = 0.50 whereas in Cauca the highest values are r = 0.41. In the following discussion only correlation coefficients superior to 0.20 will be considered. In Honduras average annual temperature is correlated for all attributes, except for balance for some clusters. The same pattern is true for elevation and average annual dew point, except for dewpoint in cluster 4 (Table 17). Average annual diurnal temperature range is only correlated with all the attributes of the entire Honduran data set and for the main attributes of cluster 3. Cluster 3 is furthermore correlated with average annual precipitation, solar radiation, slope, and northness.

In Cauca, average annual temperature, average annual dew point, average annual diurnal temperature range, and elevation are the variables higher or close to 0.20 correlated with final score and aroma (Table 18). In El Tambo-Timbio these factors are correlated with balance, body and acidity and in Inzá with cleancup, flavor, and uniformity. Average annual precipitation is correlated in El Tambo-Timbio with aftertaste, body, cleancup, and uniformity. Average annual number of dry month is correlated in Inzá with balance, body sweetness and uniformity. Slope, eastness and northness are only correlated in some instances with the sensorial attributes and mainly in El Tambo Timbio and Inzá. The remaining correlations coefficients are less than r = 0.20 in El Tambo-Timbio and Inzá.

Table 17: Correlation between environmental factors and quality in Honduras

	ATTRIBUTES	**P**	**T**	**DP**	**DTR**	**DM**	**SR**	**S**	**E**	**N**	**EL**
All data (582)	AROMA / F	-0.03	-0.42	-0.42	0.21	0.15	-0.01	0.04	-0.03	-0.03	0.42
	ACIDITY	-0.04	-0.50	-0.50	0.23	0.17	0.02	0.03	0.00	0.01	0.50
	A.TASTE	-0.02	-0.49	-0.49	0.20	0.15	0.02	0.05	-0.02	-0.01	0.50
	BODY	-0.01	-0.46	-0.46	0.21	0.16	0.02	0.01	-0.01	0.02	0.46
	FLAVOR	-0.01	-0.50	-0.48	0.20	0.16	0.02	0.06	-0.01	0.01	0.49
	FINAL S	-0.02	-0.49	-0.49	0.20	0.16	0.02	0.05	-0.01	0.00	0.49
Cluster 2 (80)	AROMA / F	0.10	-0.23	-0.23	0.07	0.01	-0.14	0.12	0.23	0.12	0.31
	ACIDITY	0.05	-0.28	-0.26	-0.03	0.04	-0.17	0.18	0.21	0.11	0.38
	A.TASTE	0.06	-0.31	-0.28	-0.04	0.02	-0.14	0.19	0.21	0.12	0.41
	BODY	0.07	-0.24	-0.23	-0.02	0.03	-0.16	0.17	0.20	0.08	0.34
	FLAVOR	0.05	-0.29	-0.27	-0.01	0.04	-0.13	0.17	0.22	0.09	0.38
	FINAL S	0.07	-0.27	-0.25	0.00	0.03	-0.13	0.15	0.23	0.11	0.36
Cluster 3 (36)	AROMA / F	0.23	-0.33	-0.32	-0.17	-0.09	0.16	0.45	-0.11	-0.30	0.27
	ACIDITY	0.20	-0.43	-0.41	0.33	-0.07	0.21	0.58	-0.07	-0.47	0.33
	A.TASTE	0.26	-0.40	-0.35	-0.28	-0.07	0.23	0.50	-0.04	-0.45	0.26
	BODY	0.12	-0.24	-0.24	-0.19	-0.03	0.33	0.57	-0.01	-0.47	0.19
	FLAVOR	0.24	-0.36	-0.34	-0.28	-0.11	0.20	0.52	-0.04	-0.44	0.25
	FINAL S	0.25	-0.38	-0.36	-0.25	-0.05	0.30	0.52	-0.01	-0.49	0.28
Cluster 4 (192)	AROMA / F	0.16	-0.24	-0.15	-0.16	-0.13	-0.8	0.15	-0.11	0.06	0.16
	ACIDITY	0.12	-0.25	-0.18	-0.14	-0.16	-0.01	0.14	-0.05	0.04	0.20
	A.TASTE	0.16	-0.26	-0.17	-0.18	-0.17	-0.02	0.15	-0.07	0.03	0.18
	BODY	0.18	-0.28	-0.18	-0.15	-0.15	-0.04	0.12	-0.05	0.08	0.20
	FLAVOR	0.17	-0.26	-0.18	-0.16	-0.16	0.00	0.14	-0.08	0.03	0.18
	FINAL S	0.18	-0.28	-0.18	-0.17	-0.17	-0.03	0.16	-0.07	0.04	0.19
Cluster 5 (150)	AROMA / F	-0.04	-0.32	-0.34	-0.15	-0.06	-0.05	-0.04	-0.09	0.10	0.37
	ACIDITY	-0.03	-0.40	-0.41	0.13	-0.06	-0.03	-0.06	-0.05	0.11	0.43
	A.TASTE	0.02	-0.35	-0.36	0.12	-0.04	-0.05	-0.03	-0.07	0.08	0.38
	BODY	-0.09	-0.39	-0.39	0.12	-0.08	-0.03	-0.07	-0.12	0.10	0.38
	FLAVOR	0.00	-0.36	-0.36	0.11	-0.01	-0.05	-0.01	-0.06	0.08	0.38
	FINAL S	0.02	-0.37	-0.37	0.11	-0.03	-0.06	-0.02	-0.07	0.09	0.40
Cluster 7 (115)	AROMA / F	0.00	-0.41	-0.37	0.10	0.07	0.03	-0.02	0.04	-0.05	0.42
	ACIDITY	-0.04	.0.43	-0.44	0.23	0.06	0.03	-0.08	0.09	-0.08	0.45
	A.TASTE	-0.02	-0.46	-0.45	0.18	0.07	0.04	-0.06	0.09	-0.08	0.49
	BODY	-0.01	-0.45	-0.42	0.17	0.06	0.03	-0.09	0.10	-0.07	0.46
	FLAVOR	.0.03	-0.46	-0.45	0.21	0.08	0.02	-0.05	0.11	-0.07	0.48
	FINAL S	-0.02	-0.46	-0.45	0.19	0.07	0.03	-0.06	0.09	-0.07	0.49

P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°), N = northness (cos(aspect*pi)/180)), E = eastness (sin(aspect*pi)/180)), and EL = elevation (masl).

Table 18: Correlation between environmental factors and quality in Cauca

		P	T	DP	DTR	DM	SR	S	E	N	EL
Cauca (88)	AROMA/ F	-0.05	-0.29	-0.27	-0.27	-0.11	0.08	0.02	0.09	-0.02	0.18
	ACIDITY	0.17	-0.15	-0.06	0.08	0.12	-0.18	-0.28	0.04	0.06	0.01
	AFTER T.	-0.01	-0.19	-0.16	-0.25	-0.10	-0.14	0.10	-0.05	0.02	0.21
	BODY	-0.02	0.08	0.10	0.01	0.07	-0.09	0.06	-0.19	0.16	-0.02
	FLAVOR	0.03	-0.14	-0.14	-0.12	-0.05	-0.04	0.06	0.00	0.06	0.16
	FINAL S.	-0.06	-0.20	-0.19	-0.20	-0.12	-0.06	-0.06	0.03	-0.02	0.22
El Tambo-Timbio (48)	AROMA/ F	0.04	-0.24	-0.25	-0.07	-0.15	0.25	-0.10	0.00	0.01	0.15
	ACIDITY	0.14	0.19	-0.20	-0.18	0.02	0.14	-0.34	0.05	-0.10	0.15
	AFTER T.	0.24	-0.15	-0.15	-0.21	-0.03	-0.06	0.00	-0.18	0.13	0.20
	BODY	-0.23	0.26	0.26	0.23	0.02	-0.25	0.19	-0.34	0.15	-0.10
	FLAVOR	0.02	-0.16	-0.16	-0.09	0.03	-0.03	0.00	-0.05	0.11	0.20
	FINAL S.	0.01	-0.16	-0.16	-0.10	0.03	0.03	-0.07	-0.17	0.05	0.23
Inzá (27)	AROMA/ F	0.09	-0.11	-0.12	0.09	-0.12	0.19	-0.34	-0.17	0.05	0.00
	ACIDITY	0.10	-0.11	-0.11	0.13	-0.04	0.16	-0.10	-0.11	0.12	0.18
	AFTER T.	-0.12	0.11	0.12	0.11	0.10	-0.13	-0.03	-0.33	-0.15	0.10
	BODY	0.04	0.05	0.01	-0.02	0.29	0.35	-0.31	0.00	0.25	-0.02
	FLAVOR	-0.17	-0.20	-0.19	0.41	-0.17	0.03	0.08	-0.51	-0.20	0.34
	FINAL S.	0.19	-0.22	-0.20	0.36	-0.14	-0.04	-0.08	-0.40	-0.13	0.27

P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°), N = northness (cos(aspect*pi)/180)), E = eastness (sin(aspect*pi)/180)), and EL = elevation (masl).

Regressions between environment and quality

Regression analyses were carried out for the final score attribute, which is a summary indicator for all the sensorial attributes. The regression analysis for Honduras confirms the results of the correlations; average annual temperature, average annual dew point, and elevation have the highest r^2 coefficients, of 0.27, 0.35, and 0.27 respectively (see grey points, equation and r^2 in Figure 12). Environmental factor averages for each quality class were calculated (see red lines, equations and r^2). The r^2 value for the environmental factor averages with its quality class is 0.94, 0.93 and 0.93 respectively. The remaining factors of the point data regression all had $r^2 < 0.05$.

The r^2 values are much higher for the regressions of the clusters than for the entire data set; this is true for both the point data regression and for the quality class regression of average annual temperature, average annual dew point, and elevation and for the majority of the remaining factors (Table 19). Class regression for cluster 7 has the highest correlation, followed by cluster 4 and cluster 3 for average annual temperature, average annual dew point, and elevation.

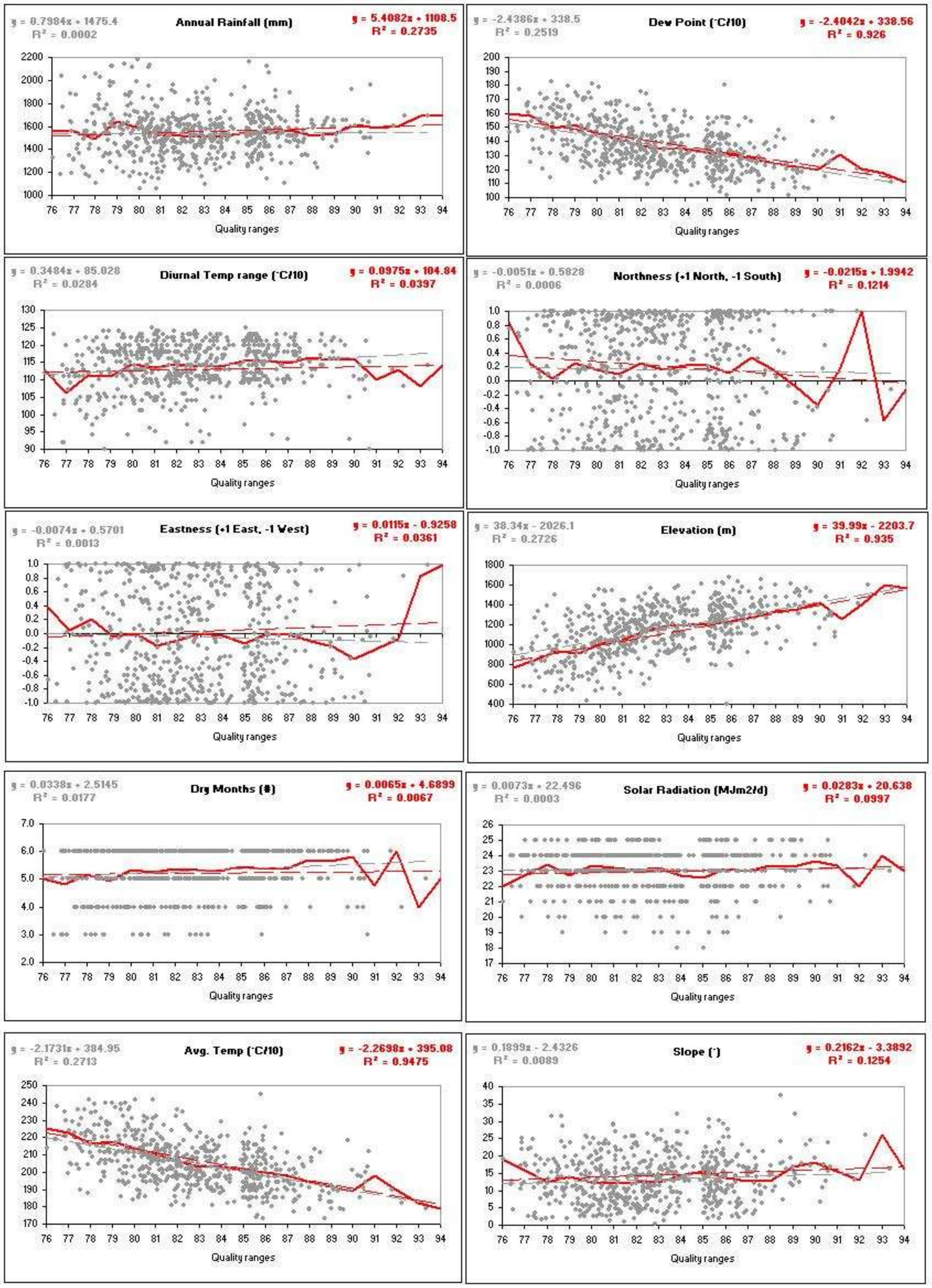


Figure 12: Regression analyses between quality and environment in Honduras.
Regression analyses were calculated of environmental factors with final score quality (grey dots and grey line) and on the final score quality class average (red line concets final score quality classes and dashed red lines is its regression) for all Honduran sites.

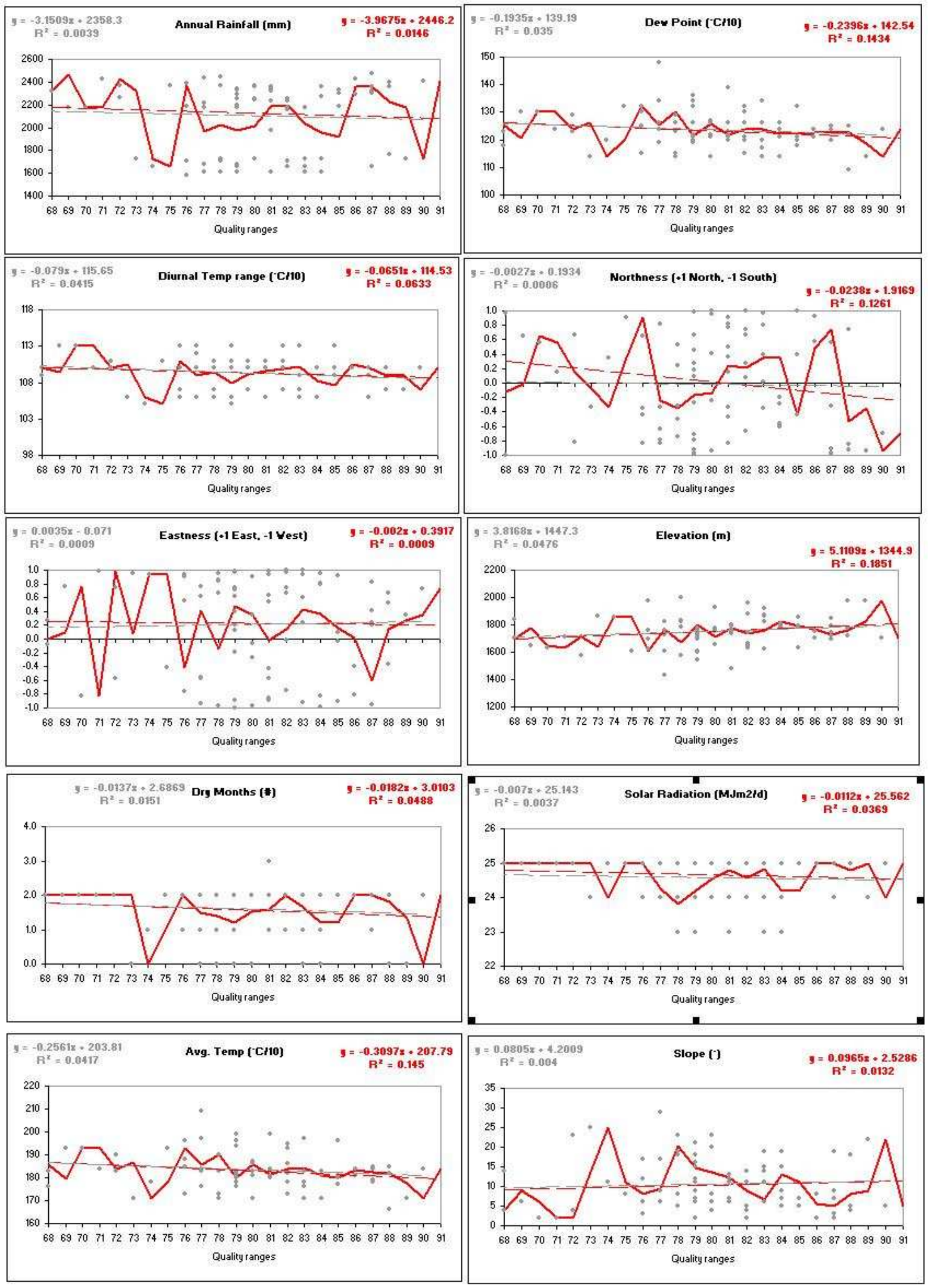


Figure 13: Regression analyses between quality and environment in Cauca.
Regression analyses were calculated of environmental factors on the data of final score quality (grey dots and grey line) and on the final score quality class average (red line concets final score quality classes and dashed red lines is its regression) for all sites in Cauca.

In Cauca, average annual temperature, average annual dew point, and elevation are the environmental factors with the highest r^2 values, 0.042, 0.035, and 0.047 respectively

(Figure 13). The r^2 value for the quality class average and its environmental factor averages are 0.14, 0.14 and 0.18 respectively. The r^2 values for Cauca are all less than 0.05. Besides the three factors above, only northness has an r^2 for the class regression greater than 0.10. In Cauca, the subsets usually have higher r^2 coefficients than the entire data set. This is true in El Tambo-Timbio for the majority of factors and in Inzá for all factors except solar radiation in the point data regression. In the class regressions, the subsets in general have lower regression coefficients than the entire data set. The tendency of higher r and r^2 values for the sub-classes than for the entire data set indicates that the subsets are more interlinked in terms of cause and effect between environmental factors and quality. The clusters in Honduras were selected statistically while the niches in Cauca were chosen based on expert knowledge, suggesting that selection by both subjective and objective means are suitable to identify niches with similar environment-quality interactions. However this pattern is more pronounced in Honduras.

Table 19: Regression between quality and environment in Honduras and Cauca
Regression of finals score with environmental factors and regression of final score classes with environmental factors averages classes were conducted with the entire Honduran data set and its clusters, and with the entire Cauca data set and the El Tambo-Timbio and Inzá niche data.

SA	RT	DS	P	T	DP	DTR	DM	SR	S	E	N	EL
Honduras	Point regression	All	0.00	0.27	0.25	0.03	0.02	0.00	0.00	0.00	0.00	0.27
		C2	0.00	0.07	0.06	0.00	0.00	0.02	0.02	0.06	0.01	0.13
		C3	0.11	0.17	0.18	0.00	0.00	0.03	0.34	0.02	0.14	0.12
		C4	0.03	0.08	0.03	0.03	0.03	0.00	0.02	0.00	0.00	0.04
		C5	0.00	0.13	0.14	0.02	0.00	0.00	0.00	0.00	0.00	0.16
		C7	0.00	0.19	0.18	0.04	0.00	0.00	0.00	0.01	0.00	0.21
	Class regression	All	0.27	0.95	0.92	0.04	0.00	0.09	0.12	0.04	0.12	0.93
		C2	0.44	0.21	0.22	0.00	0.03	0.19	0.13	0.24	0.19	0.45
		C3	0.38	0.45	0.35	0.02	0.00	0.03	0.62	0.00	0.19	0.19
		C4	0.39	0.68	0.62	0.49	0.25	0.05	0.25	0.38	0.57	0.57
		C5	0.11	0.35	0.36	0.12	0.00	0.01	0.00	0.04	0.51	0.51
		C7	0.07	0.76	0.69	0.12	0.00	0.05	0.00	0.01	0.86	0.86
Cauca	Point reg.	All	0.00	0.04	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.05
		TT	0.00	0.02	0.03	0.01	0.00	0.00	0.00	0.03	0.00	0.05
		In	0.02	0.05	0.04	0.13	0.02	0.00	0.01	0.15	0.02	0.07
	Class reg.	All	0.01	0.14	0.14	0.06	0.05	0.04	0.01	0.00	0.12	0.18
		TT	0.00	0.06	0.07	0.02	0.00	0.00	0.01	0.08	0.00	0.13
		In	0.08	0.10	0.09	0.19	0.04	0.00	0.01	0.24	0.03	0.10

SA = Study area, RT = Regression type, DS Data sets, P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°), N = northness (cos(aspect*pi)/180)), E = eastness (sin(aspect*pi)/180)), and EL = elevation (masl).

Quality class average versus environment

By plotting the final score quality class averages against the environmental factor averages for each cluster, the differences between the clusters become apparent. High beverage quality can be produced in a range of environmental conditions (Figure 14 and 15). For example, a final score quality of 92 points can be produced at a temperature range of 18 to 22°C, at an elevation of 1100 to 1300, and with a number of dry months of between 5 and 6. These results indicate that there is not just one optimum level of an environmental factor but an optimal combination of environmental factors that make a growing environment superior to another.

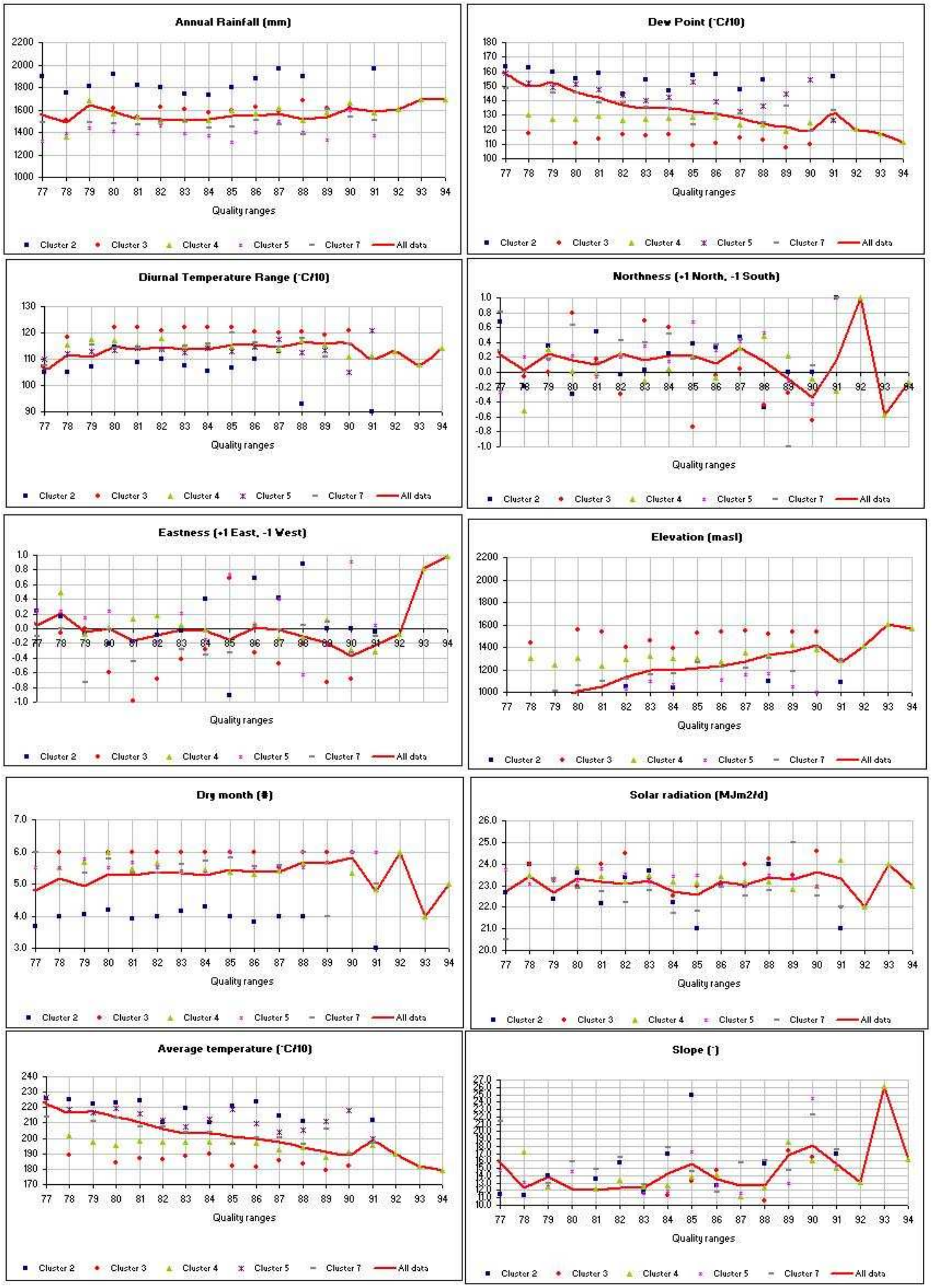


Figure 14: Average quality versus average environmental factor of Honduras.
Average quality class values for each cluster are plotted against the average environmental factor values. The red line connects the plotted values of the entire data set.

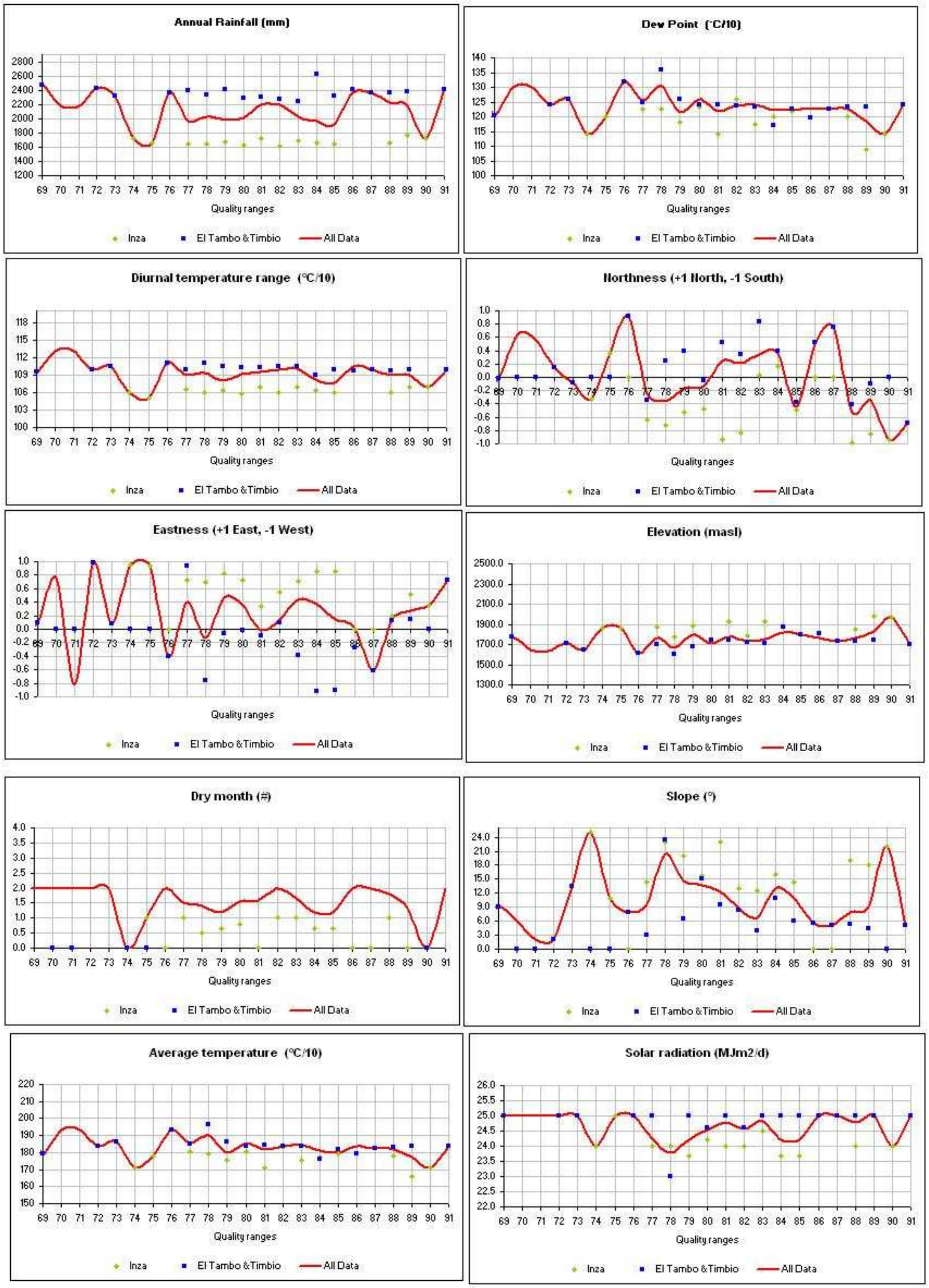


Figure 15: Average quality versus average environmental factor of Cauca.
Average quality class values for each cluster are plotted against the average environmental factor values. The red line connects the plotted values of the entire data set.

4.3 Conclusions

1. The literature reports a range of environmental factors that impact on coffee quality. Among these are the following: average annual precipitation, average annual temperature, and average annual dew point, and average annual diurnal temperature range, average annual number of dry month, solar radiation, slope, eastness, northness, and elevation.

2. In the last decade, efforts were made to identify factors that impact on coffee beverage quality. The studies were often conducted in few single sites under controlled conditions, which makes it difficult to extrapolate the results.

3. Generating data for environmental factors by GIS methodology to relate to actual coffees sampled in the field might not be as precise as controlled experiments but allows a broader coverage of information.

4. Environmental factors and coffee quality are highly variable in space. Coffee quality and environmental factors are correlated with each other.

5. The magnitude of the impact that the environmental factors have on quality is also variable, and the same factors are not always decisive. Combination of very different environmental conditions can produce high beverage quality.

6. In Honduras, correlation and regression coefficients, mainly due to elevation and temperature, are much higher than in Cauca. where the decisive factors are not as strongly correlated and are more difficult to identify.

7. Subsets within both the Honduras and Cauca data are generally more strongly correlated than are the entire data sets. This indicates that similar environments were successfully identified; the similar environments in this case being combinations of environmental factors that cause similar effects.

8. The environments were selected by means of a cluster analyses in Honduras and by expert knowledge in Cauca. This suggests that both subjective and objective means are

suitable to identify niches with similar environment quality interactions. However the patterns were more pronounced in Honduras, where the identification was based on a statistical approach.

9. Correlation and regression analyses are viable ways for a first assessment of the decisive factors for quality. As suggested by the Paretto Principles are there only some factors that are decisive for the major part of the quality.

5 MANAGEMENT QUALITY INTERACTIONS

Specific objective 2: To describe and quantify the impact of agronomic management and post-harvest processes on coffee liquor quality.

Management at the farm level is the second group of important factors in determining coffee beverage quality. Farm management is divided in agronomic management and post-harvest practices and is termed as the farmer's management interventions to influence decisive quality factors. In this chapter, firstly farm management practices and their impact on beverage quality are reviewed and secondly the variability of farm management practices is illustrated and the potential to vary them to improve coffee quality is outlined.

5.1 Impact of farm management on sensorial quality

5.1.1 Biophysical factors

Aspect has only recently been studied as a factor influencing coffee quality (Avelino, 2005). On 35 sample sites in commercial farms in two coffee growing areas in Costa Rica, east-facing slopes in the Orosi growing zone had significant impact on body and acidity, preference was also highest on east-facing slopes (Avelino, 2005). In Santa Maria de Dota, Avelino (2005) observed significant improvement for beverage quality in aroma, body, acidity and preference in coffee from east-facing slopes. Avelino's reasoning was that the east-facing slopes receive more sunlight than the remaining orientations due to the low cloud cover in the morning when east-facing slopes are fully exposed to the sun.

Soil is usually quoted as a basic factor impacting on coffee quality (Barel and Jacquet, 1994; Camargo et al., 1992; Cofenac, 2003; Illy, 2001). It is generally accepted that volcanic soils produce the best quality coffee (Griffin, 2001; Njoka and Mochoge, 1997). Griffin (2001) states that volcanic soils often have positive influence on the attributes of acidity and body. Avelino et al. (2002) state that adequate soil for coffee has light texture. Different ranges of pH are recommended according to the growing zone (Table 20).

Table 20: pH ranges for different coffee growing conditions

	Soil requirements	Region	Reference
Growing conditions	Acid pH (5.0-5.5) or slightly acid (6.0-6.5)	Equador	(Cofenac, 2003)
	pH from 4.8 -6.0	Colombia	(Cenicafé, 1979)
High quality coffee growing conditions	pH from 5.4 – 6.5	General Statement	(Njoka and Mochoge, 1997)
	pH of 5.4 to 6.5	Honduras	(Avelino et al., 2002)

Illy (2001) quotes that micronutrients frequently show a non-linear correlation between their concentration in the soil and cup quality. Another study (Foote, 1963) has shown that nutrient deficiencies may decrease cup flavor, on the other hand there is a very clear and positive link between gustative qualities and low soil fertility (Pochet, 1990). Griffin (2001) states that potassium also augments the body of a coffee and increases the weight of the bean. Avelino et al. (2002) show that low contents of calcium affect coffee quality, Cofenac (2003) states that magnesium content favors the characteristics of aroma and flavor. Cofenac (2003) also showed that high contents of nitrogen and iron in coffee soils contribute directly improved acidity of the brew. Avelino et al. (2002) found that excess aluminum affects coffee quality negatively, while Cofenac (2003) states that high contents of copper negatively affects aroma, flavor and body characteristics. The data in the present study on the effect of different catena positions on beverage quality did show higher scores for upper slope positions that supports the Pochet's (1990) findings that low soil fertility is correlated with high gustative qualities, but the differences are not large. In comparison to the other management factors, soils are very complex to assess and it is difficult to derive recommendations for direct use by the farmer for the improvement of coffee quality

5.1.2 Variety

A study conducted in Central America to compare the sensorial quality of traditional varieties such as Caturra, Pacas, Catuai, Bourbon and Pacamara with Arabica hybrids of Sudanese-Ethiopian origins did not show any significant differences (Bertrand et al., 2006). A study in Colombia did not show any consistent differences between Caturra and Colombian traditional varieties (Puerta-Quintero, 1988), however the Caturra variety is preferred by most specialty coffee roasters over the Colombia traditional varieties. There are currently some varieties that are very sought after by specific markets such as the Geisha variety by the Japanese market and the Bourbon variety by the North American market. Another study states that coffee cup qualities are determined genetically and can deteriorate in production and processing of the grain (Fajardo-Peña and Sanz-Uribe, 2003). ICO et al. (2000) argue that there is no inherently bad coffee. When coffee is of poor quality then the cause can usually be traced to poor harvesting methodology, post harvest processing, drying and handling.

5.1.3 Shade management

It has long been agreed that shade is the main factor enhancing coffee plantation sustainability in sub-optimal coffee zones (Beer et al., 1998). Recently shade cover has been shown to be beneficial in different coffee growing zones not only for its environmental services and additional income for farmers but as a means to improve coffee quality. In Costa Rica zero shade has a negative impact and 45% shade has a positive impact (Vaast et al., 2005), while in Nicaragua 45% or less had a negative effect, while 46-63% had a positive effect (Lara-Estrada, 2005). In Honduras less than 45% shade had a negative effect (Decazy et al., 2003), and in Guatemala high shade levels were positive and low shade levels had a negative impact. The optimal shade level for the 0-20°N latitude is therefore probably somewhere between 45% and 70% (Table 21).

Table 21: Shade levels and impact on quality
Reviewed studies from Central America.

Reference	Country	Positive impact	Negative impact	Observation
(Vaast et al., 2006)	Costa Rica	45% shade	0 % shade	Optimal growing zone
(Muschler, 2001)	Costa Rica	High shade level	Low shade level	Sub-optimal growing zone
(Lara-Estrada, 2005)	Nicaragua	46-63%	≤45%	Optimal growing zone
(Decazy et al., 2003)	Honduras	Not evaluated	<44%	Optimal growing zone
(Guyot et al., 1996)	Guatemala	High shade level	Low shade level	Optimal growing zone

5.1.4 Harvest management

According to specialty roasters, harvest is the critical point where quality can deteriorate or its potential can be maintained. A careful picking of only ripe cherries in contrast of stripe picking is crucial and conserves beverage quality (Barel and Jacquet, 1994). In wine it had long been demonstrated that ‘selective harvesting’, that is the split picking of fruit according to different yield and quality criteria to exploit the observed variation was beneficial terms of higher cross margins per hectar (Bramley et al., 2003). Management practices have to be site specific in order to improve coffee quality. Recently some harvest practices in coffee have been developed and their impact on quality assessed.

Fruit thinning is the elimination of parts of the fruit load before its maturation to allow a concentration of the plants' energy in fewer fruits and an increased accumulation of carbon, sugar, acids and other quality-relevant components. Vaast's (2006) study conducted in Costa Rica showed a significant improvement of preference and acidity score of trees in which the fruit had been thinned. Attributes of bitterness and astringency attributes, which the consumer does not like, decreased with decreasing fruit load. Fruit-thinning in kiwifruit (Smith et al., 1992), apples (Palmer et al., 1997), and peaches (Corelli-Grappadelli and Coston, 1991; Souty et al., 1999) has been shown to have beneficial effect on quality.

The separation of harvest time showed significant impact on beverage quality in a study conducted in Costa Rica (Vaast and Bertrand, 2005). Beverage quality of early and peak harvest was significantly higher than late harvest for acidity and preference and significantly lower for astringency and bitterness. Additional results presented in the same study confirmed that higher quality was reached for early and peak harvest in the case of acidity and preference for the varieties Caturra and Costa Rica 95 at altitudes of 700, 800, 1100, 1180 and 900, 1000, 1180, 1200, 1350, 1400 masl.

Separation of the harvest according to position of the fruit in the canopy was studied in Costa Rica (Bertrand et al., 2004) In five-year-old trees there was a significant difference between fruit harvested from the upper canopy where the beverage quality was significantly higher for acidity and overall standard compared with the middle and lower canopy. There were no differences in beverage quality with canopy position in three-year-old trees.

5.1.5 Post-harvest practices

Specialty coffee quality is highly dependent on careful post-harvest processing (Menon, 1992). The post-harvest processing may be either by a dry or a wet procedure. Dry processing is used for Brazilian Robusta and Arabica, while wet processing is mainly used for Arabica coffees and only rarely for Robustas. Dry processing consists of drying the beans immediately after harvest without removing the pulpy exocarp that surrounds the bean. The exocarp is dried until it is dehydrated and is thereafter removed mechanically during the hulling process. In wet processing, the exocarp and parts of the mucilage are removed mechanically. The remaining mucilage is then removed either by fermentation or by another mechanical process (BECOLSUB). The wet process gives a shorter drying period, a more attractive-looking grain, and finer coffee aromas (Barel and Jacquet, 1994).

Wet processing is differentiated between the traditional method, which includes fermentation, and the ecological method BECOLSUB (abbreviation of the Spanish for ecological post-processing and its products). In the BECOLSUB process beans are centrifuged until there is no more mucilage attached to the bean. Fajardo and Sanz (2003) showed that physical quality of the coffee is improved when processing the beans with the BECOLSUB method compared with fermentation. BECOLSUB produces a smaller proportion of beans with adhering shell and mucilage, as well as fewer impurities and less almond coffee with first and second order defects. In addition BECOLSUB uses much less water leading to substantially less contamination of rivers and streams in the coffee-growing areas. Mechanical removal of mucilage improves the acidity and body of coffee without affecting the aroma as long as the coffee is dried immediately (Griffin, 2001). There are many ways that bad processing can cause decreased beverage quality and give serious defects such as stinker, amongst which the most prominent are delayed processing after harvest and drying the harvested fruit in thick layers (Kamau, 1977).

Fermentation is the microbiological process of mucilage removal. The coffee is piled up in fermentation basins or bags and the process lasts for 12 – 30 hours depending on the climatic conditions. Traditionally, producers determine that mucilage fermentation is “complete” by manual inspection of the fermenting mass. Before completion, the intact mucilage layer is slippery, and the parchment coffee readily slides over itself. But at completion, the coffee is no longer slippery, the mucilage layer is loose and can be completely washed off. Coffee produced by the traditional wet method using microbial mucilage removal has given better quality than the mechanical methodology, the coffees had better aromatic quality with floral, fruity and caramel tones (Gonzalez-

Riosa et al., 2006). "Over-fermentation" is generally considered as detrimental to coffee quality (Puerta-Quintero, 1999), and controlling it is crucial to enter the specialty coffee market. Systematic measurement of pH can predict when fermentation is complete and can indicate when over-fermentation may be occurring. The value of pH = 4.6 was observed to be the critical point in a study in Nicaragua (Jackels and Jackels, 2005). Over-fermentation of coffee fruit produces a highly displeasing sour sensation on the tongue –the result of enzymatic activity in the green coffee beans changing the sugars to acetic acid (vinegar) (Lingle, 2001).

There is a great variety of mechanisms to dry parchment bean coffee; and here they are divided into four groups:

(i) Drying under sun on the floor,
(ii) Drying under sun in mobile units to protect the beans from weather events,
(iii) Drying under sun protected against the weather by a kind of cover, and
(iv) Mechanical drying in a silo.

A study from Java showed that coffee dried in the sun had better flavor characteristics than coffee dried mechanically. In India, for example, coffee is dried in the monsoon winds and provides a good quality coffee sought by European markets (Nagabhushana R., 1989). Griffin (2001) states that final taste of coffee will greatly differ depending on the drying method, for example, coffee dried on clay patios can have a clay-like earthy taste. Cuppers often identify defects caused by drying on contaminated surfaces. For example, coffee can have a plastic taste from being dried on plastic sheets, or have a corn flavor in the cup because of contamination due to corn being dried along with the coffee.

5.2 Quantification of variable farm management

5.2.1 Biophysical factors

Aspect is a variable that obviously cannot be directly altered by the farmer but by separating the beans depending on the aspect of the field on which they were grown, farmers can at least manage the influence of aspect. The majority of coffee farms are on hillsides with very heterogeneous terrain so that even small farms often have distinctly different aspects. In Inzá, there are very few slopes facing south or southwest while in El Tambo-Timbio slopes are fairly homogenously distributed, with somewhat fewer east and southeast facing slopes (Figure 16).

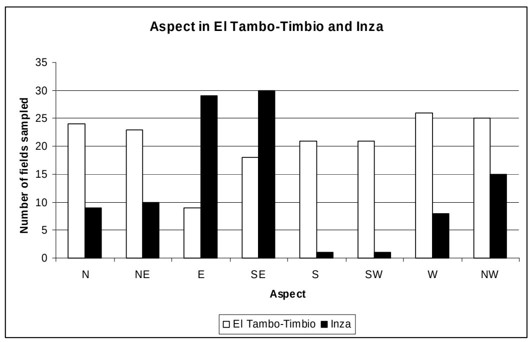


Figure 16: Aspect of farms in Cauca.

The soils of the sampled sites in El Tambo-Timbio are mainly Inceptisols, although there are some Entisols, Entisols-Inceptisols and Inceptisols-mollisols-alfisols. In Inzá the soils are Entisols-Inceptisols (Figure 17). All are mineral soils. Inceptisols have minimal horizon development, although they are more developed than Entisols, which lack developed horizons. Alfisols are relatively low in organic matter with relatively high base saturation and Mollisols have thick, dark surface horizons relatively high in organic matter and high base saturation.

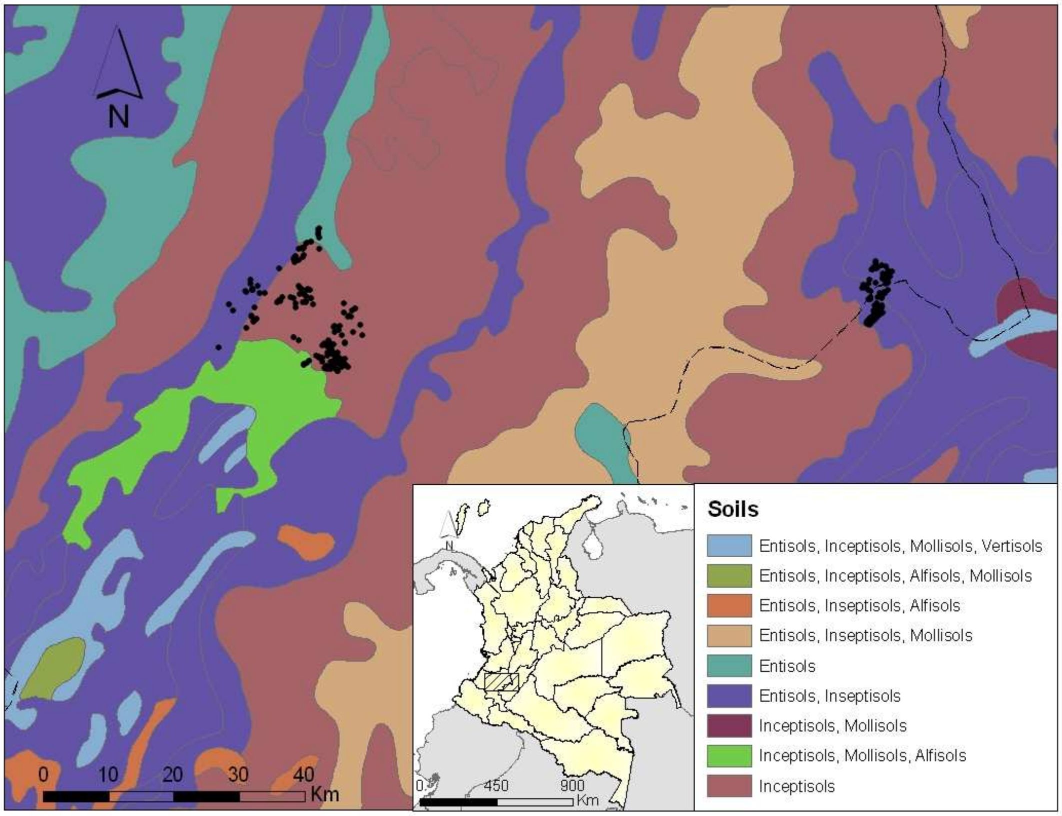


Figure 17: Soils of farms in Cauca.
The map shows sampling sites in El Tambo-Timbio (west) and Inzá (east), map adapted from (IGAC, 1983).

5.2.2 Variety

In Colombia it is forbidden to plant Robusta coffees (*Coffea canephoraa)*, therefore all the varieties are Arabica (*Coffea arabica)* species. The 270 sampled farms in Cauca 194 are mainly planted with Caturra variety, followed by 31 with the Colombia variety and 25 with Caturra and Colombia mixed. Caturra variety is sometimes mixed with Typica (3 sites), San Bernardo (3) and Bourbon (1). There are also some farms with only San Bernardo (13) variety and some with only Typica (3) (Figure 18)

.

In El Tambo-Timbio 168 and in Inzá 102 farms were sampled. Both areas have nearly the same percentage planted of the Caturra variety, 70% in El Tambo-Timbio and 73% in Inzá. The Colombia variety comprises 15% and 4% in El Tambo-Timbio and Inzá respectively. In El Tambo-Timbio proportionally more farms have mixed varieties although there are few farms where Colombia is mixed with other varieties. There is a distinguishable clustering of the Colombia variety (Colombia only or rarely mixed with Caturra) in the south-east and north east. In Inzá there are only five sites where Colombia or Colombia mixed with Caturra was planted; there is a clustering distinguishable of San Bernardo, Typica and Caturra mixed with other varieties in the south (Figure 18).

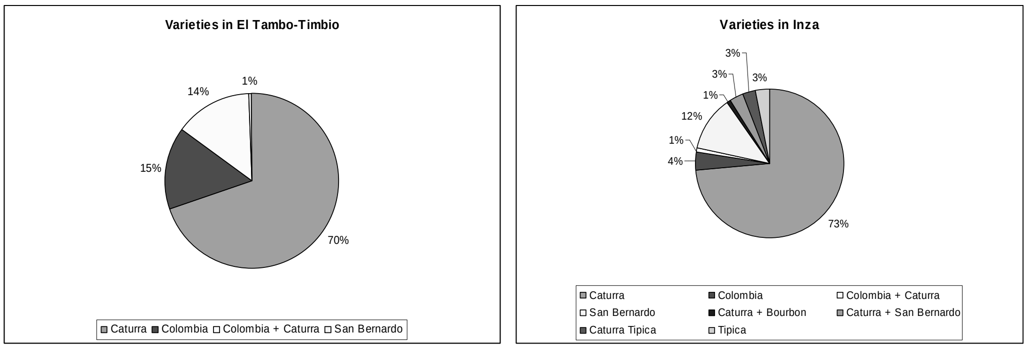


Figure 18: Coffee varieties distribution in Cauca.
The graph is read clockwise. Caturra refers in El Tambo-Timbio to 70% and in Inzá to 73%.

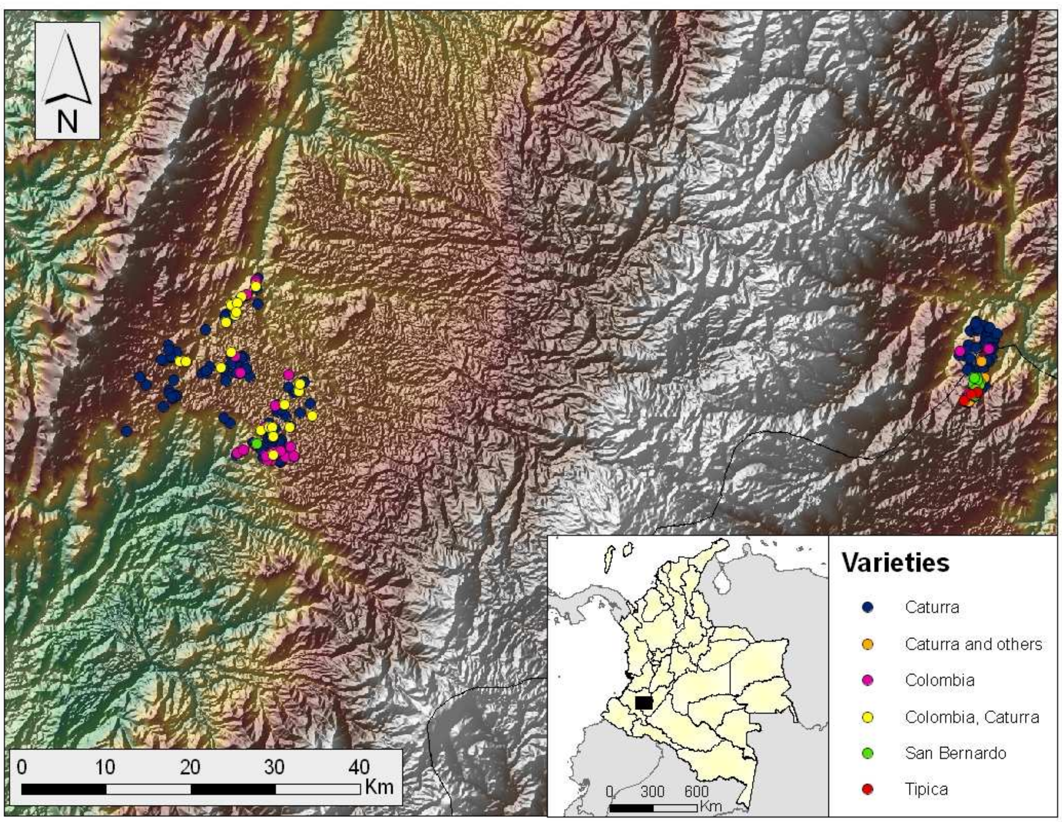


Figure 19: Varieties in farms in El Tambo-Timbio (west) and Inzá (east).

5.2.3 Shade management

Shade management in Cauca is variable, depending on the farmer's diversification and income strategy. In the 270 farms surveyed 87% have some kind of shade in their coffee plantation and only 13% cultivate coffee in full sun. In El Tambo-Timbio 95% of the coffee fields have some kind of shade while in Inzá only 75% of the fields have shade (Figure 20).

In El Tambo-Timbio 10 % use only one species of shade, 33% use two species, 21 % three species, 15 % four species and 16 % use five species or more (Figure 20). In Inzá 25 % use only one species of shade specie, 21% two species, 13 % three species, 7 % four species and 9 % use five species or more.

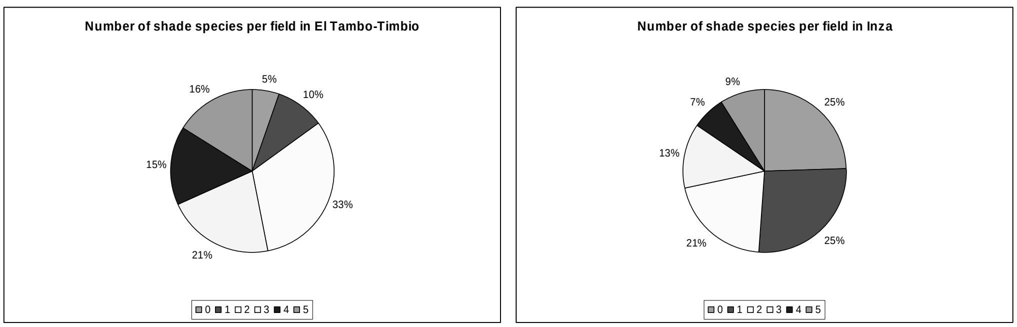


Figure 20: Shade species distribution in El Tambo-Timbio and Inzá.
The graph is read clockwise, one specie per field refers in El Tambo-Timbio to 10% and in Inzá to 25%.

A spatial pattern is distinguishable. Sites with a higher number of shade species are often clustered; In El Tambo-Timbio in the southeast and the west and in Inzá in the south (Figure 21). This appears to be farmers in a given local area tend to adopt similar practices and strategies.

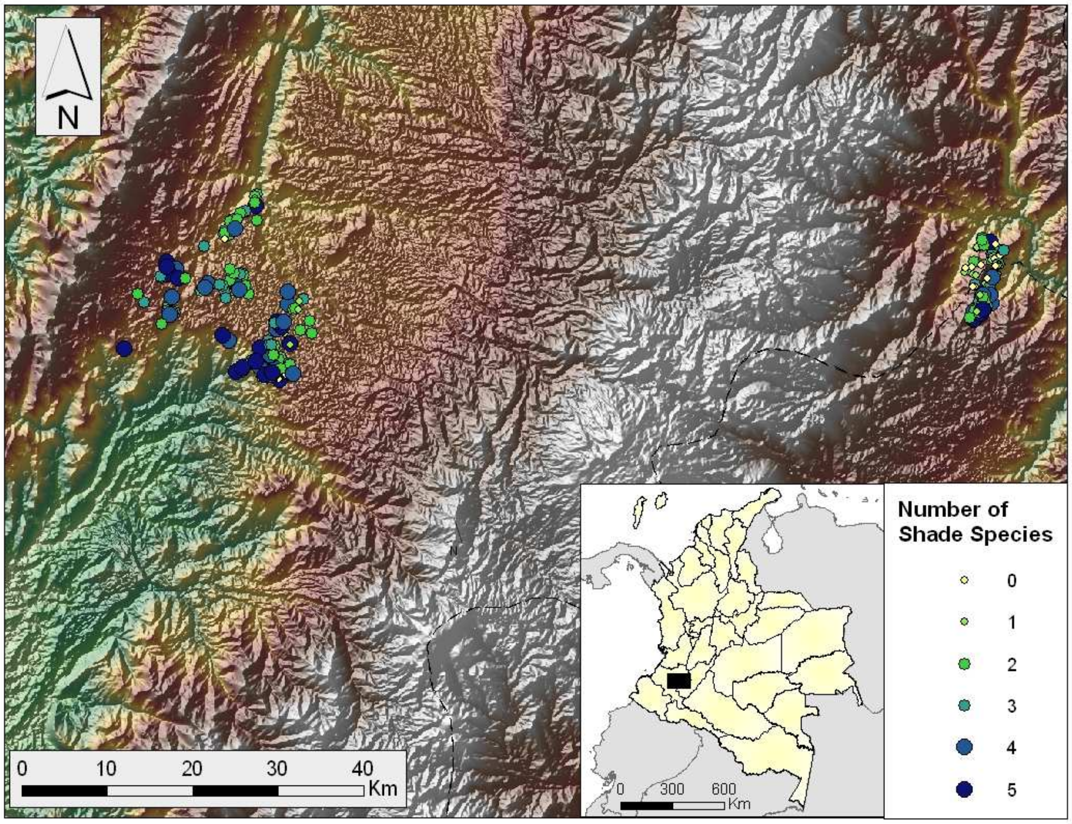


Figure 21: Number of shade species in the surveyed farms.

5.2.4 Harvest management

A survey conducted by Cenicafé (Figure 22) shows the harvest periods and peaks in the different coffee-growing areas of Colombia. In the the south, north and northwest there is only one principle harvest, while in the center of the country there are two principle harvests. The harvest period in all the areas is distributed over at least four months, and since coffee is harvested every 3-5 weeks, four to six harvests are usual. Grain from the different harvests can be kept separate to maintain uniform quality.

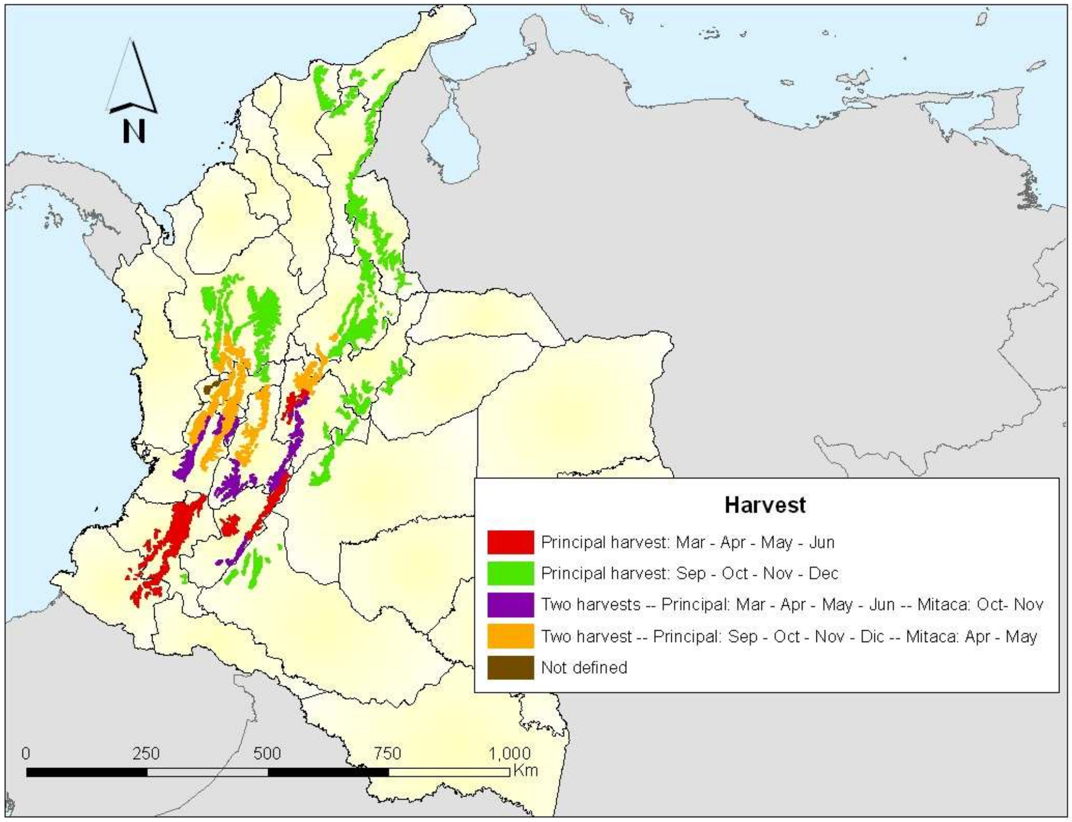
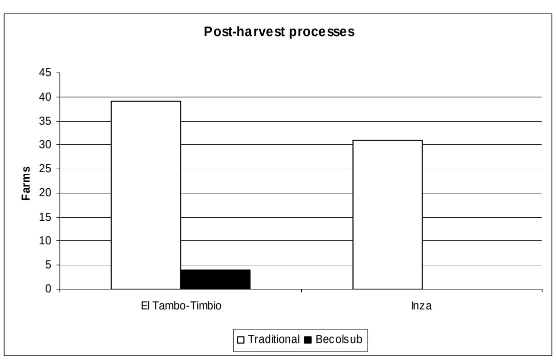


Figure 22: Coffee harvest periods in Colombia.
Map adapted from (Cenicafé, 1997).

5.2.5 Post-harvest practices

Only 5 % of the farmers work with the BECOLSUB method, the remaining 95 % remove the mucilage by traditional fermentation. The 5 % using BECOLSUB are all from El Tambo-Timbio (Figure 23).



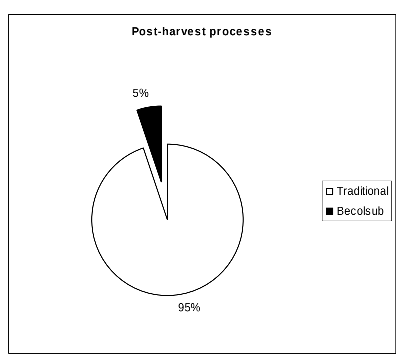


Figure 23: Post-harvest processes in Cauca.
The graph on the left shows traditional processing versus BECOLSUB in El Tambo-Timbio and Inzá, the graph on the right the percentage of traditional versus BECOLSUB processing.

The condition of the farmers' post-harvest equipment and the working environment was surveyed by asking farmers to choose between:

(i) Equipment is in good condition and the working environment is clean and suitable for coffee processing;
(ii) Neither the equipment's performance nor the working environment is entirely satisfactory; and
(iii) Both the equipment and working environment needs to be improved.

The general pattern in both growing areas is similar however differences were more pronounced in El Tambo-Timbio. The majority of the farmers believe that neither the status of their equipment nor the working environment is entirely satisfactory followed by many who believe that they are good and a small minority who admit they need improvement (Figure 24).

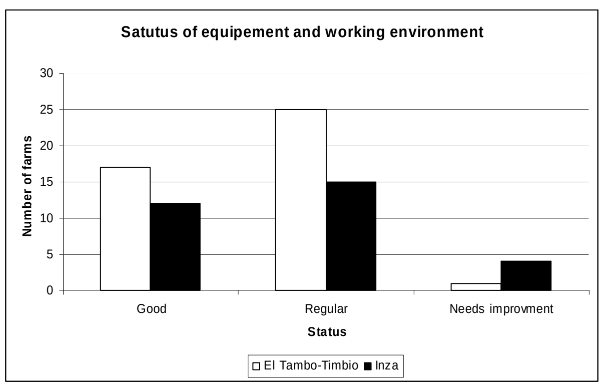


Figure 24: Status of equipment and working environment in Cauca farms.

Coffee is dried in a variety of ways, which can be summarized in four major categories (Table 22):

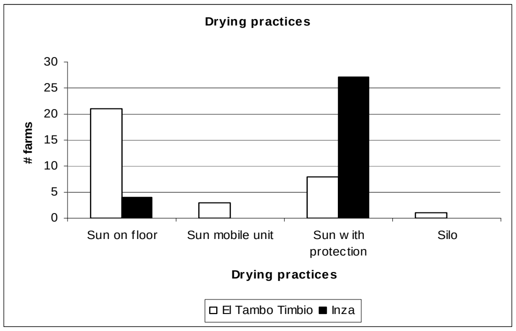
(i) Drying in the sun on a floor;
(ii) Drying in the sun under mobile units to protect the beans from unexpected rain;
(iii) Drying in the sun protected by some kind of light penetrable cover; and
(iv) Mechanical drying in a silo.

Drying in the sun on the ground has the disadvantage that the coffee has to be gathered up each time before it rains. Often the coffee gets wet because it could not be gathered on time, which can spoil the quality. Mobile sun dryers are more advanced systems of drying under the direct sun. The advantages are that the coffee can be rapidly removed to shelter from rain and that the coffee is not in direct contact with the floor. Sun drying under a sun-penetrable cover is an efficient and natural way of drying. These installations are usually built so that they allow a constant air flow and that the coffee never gets wet or in contact with the soil.

Table 22: Categories of drying methods

Category	Type	Description
Sun dried on the floor	On a clay floor	Most simple way of drying. Danger of contamination.
	On a cement floor	Most reasonable way of floor drying
	On a plastic sheet	Danger of contamination
	On fertilizer or other bags	High danger of contamination
	On wood or bamboo	Most reasonable way of floor drying
Mobile sun dryer	Casa Elda	Casa Elda are drawers that are built in the roofs of farmers' houses, so that the drawers can be quickly moved under the roof to protect the coffee of rain.
	Paceras or colectas	Free standing drawers with a roof. Similar to Casa Elda
	Sieves	Sieves with wooden mark are used dry coffee and when rain threatens they are piled up in a dry place.
Sun dried under some kind of protection	Parabolica con polisombra	Plastic tunnel over black sieves that allow the air circulation through the grains. Mainly used in the Cauca department (El Tambo-Timbio).
	Camion	A plastic tunnel over firm ground that only allows air circulation through the tunnel. Mainly used in the Huila department (Inzá).
Silo	Sisco	Heat is produced by burning the hulls of the beans removed during the hulling process
	Charcoal	Heat is produced by burning. Danger of contamination
	Propane	Heat is produced by burning propane.
	Diesel	Heat is produced by burning Diesel. Danger of contamination

More than 50 % of farmers dry in the sun with penetrable cover protection, 39% still dry on the floor, and only 5% have a mobile drying unit and 2 % a silo dryer (Figure 25). In El Tambo-Timbio and Inzá drying on the floor under direct sunlight and under some kind of protection is common. A few farmers have mobile drying units or a silo. In El Tambo-Timbio the cheapest and easiest way of drying, in the sun on the floor, is most common whereas in Inzá farmers more frequently dry their coffee under some protection.



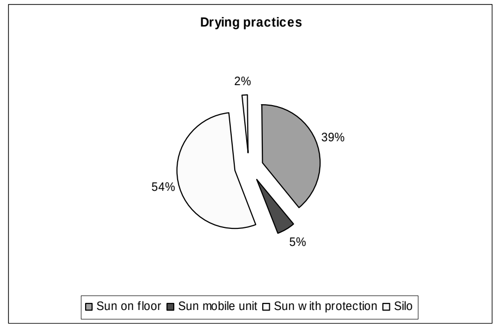


Figure 25: Drying practices in Cauca.

The graph on the left shows the different drying types in El Tambo-Timbio and Inzá, the graph on the right the percentage of the drying processes.

5.3 Conclusions

1. Farm management practices such as control of biophysical factors, varieties, shade management, and post-harvest practices have been studied and are reported as decisive for coffee quality.

2. Farm management practices are highly variable between the growing niches. In Inzá slope aspects are more homogenous than in El Tambo-Timbio. Soils are more variable in Inzá, where more fields have shade, there are more shade species per farm and there is more mixture of coffee varieties. Post-harvest practices also differ between both niches.

3. Agronomic management practices vary within niches; patterns of distribution of varieties and shade management are clearly recognizable. Farmers closer to each other are more likely to have similar shade species and variety management than farmers further apart. Shade levels do not follow this pattern.

4. Post-harvest practices are very homogenous within the niche. The question is however if these adaptations were made consciously and in function of the realization of the competitive advantage.

5. The bottom line question is,: “What is the adequate farm management to match with a given natural environment? How can farmers realize their comparative advantage of a beneficial natural environment and, with suitable management practices, convert it into a competitive advantage?”

6 SPATIAL DECISION SUPPORT TOOLS

Specific objective 3: To compare and evaluate spatial analyses tools for the identification of high quality coffee niches.

The objective of this chapter was firstly to compare the spatial decision support (SDS) tools MaxEnt, CaNaSTA, Domain and BioClim, where CaNaSTA is a SDS tool that was adapted to predict coffee quality for this research. The second objective was to evaluate the SDS tools using a data set of coffee quality from Honduras. The third objective was to validate CaNaSTA and to present a case study using a data set of the Cauca department in Colombia. The final objective was to discuss the utility of the approach for farmers. For detailed description of the methods refer to Chapter 3 on methodology.

6.1 Model comparison

A great variety of algorithms and models exist to predict the geographic distribution of species. Sometimes data of both presence and absence are available so that general-purpose statistics can be used. For an overview of the available techniques used with these data see (Corsi et al., 2000; Elith, 2002; Guisan and Zimmerman, 2000; Scott et al., 2002). When only data of presence are available, which is often the case for poorly-sampled tropical regions, different models and algorithms are required. Coffee quality is a function of the environmental factors and is highly variable in space. If models originally developed for species distribution could be used to identify and map coffee quality, this becomes a researchable issue. Frequently used models that are based on very distinct mathematical algorithms were therefore compared to assess their performance.

6.1.1 CaNaSTA

The SDS tool, crop niche selection in tropical agriculture (CaNaSTA), was initially developed to suggest to smallholder farmers in the tropics niches for forage species. During the research presented here it was adapted to predict coffee quality. The engine used in developing CaNaSTA was Bayesian probability modeling. Bayesian methods provide a “formalism for reasoning under conditions of uncertainty, with degrees of belief coded as numerical parameters, which are then combined according to rules of probability theory” (Pearl, 1990). A simple Bayesian model defines prior and conditional probability distributions and combines these to calculate posterior probabilities for each possible outcome. In other words, CaNaSTA compares the environmental factors for each pixel with sites where evidence is known about environmental factors and coffee quality. It then assigns a probability value depending on the similarity of the pixel with the evidence sites. The probability distributions may be derived from data, set by expert opinion or defined from a combination of data and expert opinion.

6.1.2 Statistical approach and algorithms

The idea of MaxEnt is to estimate a target probability distribution by finding the probability distribution that has maximum entropy (Phillips et al., 2006) by working in cycles during which it adjusts the probabilities until it arrives at a solution. In contrast, CaNaSTA assigns to each cell a conditional probability based on the known prediction response relations of the evidence data. MaxEnt and CaNaSTA make both use of prior probabilities, interpreted as a description of what is known about a variable in the absence of some evidence. The Domain algorithm averages the expression of the environmental evidence variables and searches for similar sites (Carpenter et al., 1993; Hijmans et al.), which causes a loss of detail in the environmental factor combination variability. The BioClim algorithm looks for pixels that fall within the multidimensional environmental range of the occurrence data (Hijmans et al.). All pixels that fall within the range are considered to be suitable. Due to the broad value range of the variables vast areas are identified as suitable, and often these predictions overestimate the reality. Bioclim does not take into account different combinations of environmental factors.

6.1.3 Ease of use and speed of modeling

MaxEnt is easy to run and use, but the interpretation requires a through knowledge of the model. On the other hand, CaNaSTa is easy to interpret but needs expertise in setting up the model since everything is user defined. Domain and Bioclim are straightforward and easy to interpret. Due to its cyclic process, MaxEnt is the most time consuming model to run, followed by CaNaSTA. Domain and BioClim both run fast because their algorithm takes up less memory.

6.1.4 Data, format, resolution and outliers

MaxEnt requires its own data sets in both shape file and ASCII format, CaNaSTA requires shape files and grd formats, both work with data of any resolution. Domain and BioClim have their own built-in data sets, but user defined data sets in shape file and grd format can also be used. The resolution of the built-in data sets is 10, 5 and 2.5 arcminutes (18, 9, 4.5 km near the equator); however data at other resolutions works satisfactorily. Bioclim and Domain have a percentile function incorporated that allows eliminating outliers, since their algorithms are very sensitive to outliers.

6.1.5 Model comparison overview

In Table 23 the technical model specifications are compared. The models are ordered from left to right according to their algorithm complexity.

Table 23: Model comparison overview

	MaxEnt	**CaNaSTA**	**Domain**	**BioClim**
Statistic approach	Maximum entropy (MaxEnt) method	Bayesian statistic	Gower point-to-point similarity metric	Boxcar environmental envelop algorithm
Algorithm	Maximum entropy that estimates the probable distribution of species (quality) by finding the distribution of maximum entropy.	Conditional probability layer from predictor variables against response classes is calculated.	Mean over all climate variables define Gower similarity indicator	Max and min values of environmental factors define multidimensional envelop
Ease of use	Easy to run stand alone software. Interpretations need broader statistical and mathematical knowledge.	Analyses are user defined and need preparations and expertise.	Easy to work with default data, more time-consuming for analyses with own data.	Easy to work with default data, more time-consuming for analyses with own data.
Speed of modeling	Performs slowest (three times slower than Domain)	Performs slowly (two times slower than Domain)	Perform fastest	Performs slightly slower than Domain
Data	Any own data	Any own data	BioClim in-built climatic layers[1] from the WorldClim database and own data.	BioClim in-built climatic layers[1] from the WorldClim database and own data.
Data format	ESRI and ASCII	Shape files and grd	Shape files and grd	Shape files and grd
Resolution	Any	Any	Any and in-built 10, 5 and 2.5 minutes of arc (18, 9, 4.5 km)	Any and in-built 10, 5 and 2.5 minutes of arc (18, 9, 4.5 km)
Sensitivity to outliers	No option	No option	Choice of outlier elimination	Choice of outlier elimination

6.2 Model evaluation and validation

6.2.1 Model precision

The four models were compared using three different combinations of evidence data and three replications for each combination and model. The indicators of comparison are the area under curve (AUC) and the Kappa values, which both assess if a prediction is significantly different than might be expected by chance.

The CaNaSTA AUC and Kappa results are statistically significant different to random predictions for quality A and the three input combinations (Table 24). The AUC values indicate an excellent discrimination and the Kappa values a moderate discrimination of the CaNaSTA model. Domain and BioClim AUC and Kappa values indicate moderate to no agreement, the latter that the predictions are no better than chance estimates. Maxent values are even lower and do clearly indicate that the predictions are no better than chance estimates. There was no apparent difference in the prediction performance of the different input combinations.

The CaNaSTA ROC AUC and Kappa results for quality AA show that the majority of analyses are statistically significant different from random predication, but the AUC Kappa values are substantially lower and only represent for AUC a moderate and for Kappa a poor to fair agreement (Table 25) . This might be because it is easier to discriminate extreme qualities such as A than qualities lying in the centre of the distribution such as AA. The remaining models show low AUC and Kappa values, whereas the Maxent values are still slightly higher than the ones for Domain and Bioclim, all of them indicate no discrimination from random predictions.

The CaNaSTA ROC AUC and Kappa results for quality AAA show a similar pattern as for quality A, that is the results are statistically significantly better than random predictions for the three input combinations (Table 26). The AUC values indicate an excellent discrimination and the Kappa values a moderate discrimination of the CaNaSTA model. The second best model for the discrimination of the AAA qualities is MaxEnt with moderate AUC discrimination and poor to fair agreement for Kappa values, that is the discrimination is statistically significant. The results for Domain and BioClim do not show a significant discrimination, either for AUC or for Kappa values.

In general there is no improvement in the predictions with increasing numbers of input variables, with the exception of the predictions with MaxEnt for quality A. These findings support Paretto's concept that only a small number of factors is responsible for the majority of causes. In the case of coffee in Honduras the factors are elevation and the interlinked temperature regimes. Kappa and AUC values tend to by highest for quality AAA, it seems that it is easier to distinguish factors responsible for higher quality coffee than those factors responsible for lower quality coffee. This also means that the environment for very high quality is different than that for average or low quality. This finding supports the hypothesis that there exist speciality coffee niches that will be discussed later in this chapter.

Table 24: Model accuracy for quality A predictions
Predictions were conducted with varying predictor combinations and evaluated by ROC AUC and KAPPA indicators.

M[1]	EF[2]	R[3]	AUC[4]	SE[5]	*z*[6]	*p*[7]	K[8]	V[9]	z[10]	P[11]
MAXENT	ALL[12]	1	0.41	0.08	-1.15	0.25	-0.20	0.02	-1.58	0.94
		2	0.54	0.08	0.59	0.56	0.03	0.02	0.26	0.40
		3	0.51	0.08	0.08	0.94	-0.06	0.02	-0.51	0.69
	D&A[13]	1	0.31	0.07	-2.57	0.01	-0.30	0.02	-2.36	0.99
		2	0.48	0.07	-0.22	0.82	-0.10	0.02	-0.77	0.78
		3	0.46	0.08	-0.49	0.62	-0.13	0.02	-1.04	0.85
	EL[14]	1	0.30	0.07	-2.79	0.005	0.13	0.02	0.79	0.21
		2	0.39	0.08	-4.08	<0.0001	-0.26	0.01	-2.14	0.98
		3	0.42	0.08	-1.06	0.29	-0.33	0.01	-2.73	0.99
CaNaSTA	ALL	1	0.80	0.06	4.92	<0.0001	0.46	0.01	4.08	0.00002
		2	0.80	0.06	5.08	<0.0001	0.46	0.02	4.09	0.00002
		3	0.80	0.06	4.91	<0.0001	0.36	0.01	3.05	0.001
	D&A	1	0.81	0.06	5.18	<0.0001	0.53	0.12	4.88	<0.00001
		2	0.78	0.06	.80	<0.0001	0.46	0.01	4.09	0.00002
		3	0.82	0.06	5.61	<0.0001	0.46	0.01	4.08	0.00002
	EL	1	0.82	0.06	5.54	<0.0001	0.53	0.01	4.88	<0.00001
		2	0.81	0.05	5.76	<0.0001	0.40	0.14	3.38	0.0004
		3	0.83	0.06	5.73	<0.0001	0.53	0.01	4.81	<0.00001
DOMAIN	ALL	1	0.55	0.04	1.21	0.22	0.1	0.04	0.51	0.30
		2	0.50	0.04	0.00	1.00	0.00	0.05	0.00	0.50
		3	0.50	0.04	0.00	1.00	0.00	0.04	0.00	0.50
	D&A	1	0.48	0.03	-0.57	0.57	-0.03	0.06	-0.13	0.55
		2	0.53	0.04	0.93	0.35	0.07	0.04	0.32	0.37
		3	0.50	0.03	0.00	1.00	0.00	0.05	0.00	0.50
	EL	1	0.48	0.02	-0.99	0.32	-0.03	0.06	-0.12	0.55
		2	0.52	0.02	1.03	0.30	0.03	0.06	0.14	0.44
		3	0.52	0.02	0.99	0.32	0.03K	0.06	0.13	0.44
BIOCLIM	ALL	1	0.43	0.06	-1.07	0.28	-0.13	0.02	-0.86	0.80
		2	0.48	0.06	-0.26	0.79	-0.03	0.02	-0.25	0.60
		3	0.51	0.06	0.26	0.79	0.03	0.02	0.24	0.40
	D&A	1	0.50	0.05	0.00	1.00	0.00	0.04	0.00	0.50
		2	0.60	0.05	2.11	0.03	0.20	0.28	1.19	0.11
		3	0.58	0.05	1.81	0.07	0.16	0.03	0.94	0.17
	EL	1	0.48	0.04	-0.44	0.66	-0.03	0.05	-0.14	0.56
		2	0.60	0.04	2.3	0.02	0.20	0.03	1.15	0.12
		3	0.55	0.04	1.38	0.17	0.10	0.04	0.48	0.31

1 Models, 2 Environmental factors, 3 Repetition, 4 Area under the ROC curve estimates if the prediction is significantly different as by chance (AUC ≤0.5), 5 Standard Error, 6 *z* statistic, 7 *p* probability indicating the significance difference from the critical AUC = 0.5, 8 Kappa statistic assesses the extend to which the model predicts by at a rate higher than by chance (0= no agreement to 1 = full agreement), 9 Kappa variance, 10 z-statistic for Kappa, *p* probability for Kappa, 12 All ten environmental factors, 13 only annual average dew point and temperature, 14 only elevation.

Table 25: Model accuracy for quality AA predictions
Predictions were conducted with varying predictor combinations and evaluated by ROC AUC and KAPPA indicators.

M[1]	EF[2]	R[3]	AUC[4]	SE[5]	*z*[6]	*p*[7]	K[8]	V[9]	z[10]	P[11]
MAXENT	ALL[12]	1	0.54	0.05	0.73	0.46	0.01	0.01	0.17	0.43
		2	0.58	0.05	1.60	0.11	0.09	0.01	1.02	0.15
		3	0.57	0.05	1.36	0.17	0.10	0.01	1.19	0.11
	D&A[13]	1	0.54	0.05	0.84	0.40	0.03	0.01	0.34	0.36
		2	0.58	0.05	1.75	0.08	0.17	0.08	1.99	0.02
		3	0.57	0.05	1.48	0.14	0.04	0.01	0.511	0.30
	EL[14]	1	0.53	0.05	0.58	0.56	-0.04	0.01	-0.51	0.69
		2	0.57	0.05	1.48	0.14	0.11	0.07	1.37	0.08
		3	0.55	0.05	1.01	0.31	0.04	0.01	0.51	0.30
CaNaSTA	ALL	1	0.63	0.05	2.70	0.047	0.14	0.01	1.72	0.04
		2	0.63	0.05	2.65	0.007	0.23	0.01	2.80	0.002
		3	0.67	0.05	3.58	0.0003	0.26	0.01	3.17	0.0007
	D&A	1	0.56	0.05	1.23	0.22	0.16	0.01	1.89	0.03
		2	0.58	0.05	1.74	0.081	0.05	0.01	0.68	0.24
		3	0.61	0.05	2.31	0.02	0.20	0.01	2.43	0.0074
	EL	1	0.63	0.05	2.85	0.004	0.16	0.01	1.89	0.03
		2	0.65	0.05	3.20	0.001	0.22	0.007	2.62	0.004
		3	0.71	0.04	0.79	<0.0001	0.28	0.01	3.56	0.0002
DOMAIN	ALL	1	0.49	0.04	-0.20	0.83	-0.01	0.01	-0.12	0.54
		2	0.55	0.03	1.51	0.13	0.10	0.01	0.88	0.18
		3	0.50	0.03	0.00	1.00	0.00	0.01	0.00	0.50
	D&A	1	0.49	0.01	-1.01	0.31	-0.01	0.03	-0.08	0.53
		2	0.49	0.01	-0.45	0.65	-0.01	0.03	-0.09	0.53
		3	0.49	0.02	-0.56	0.57	-0.01	0.03	-0.09	0.53
	EL	1	0.51	0.07	1.03	0.30	0.01	0.03	0.09	0.46
		2	0.51	0.01	1.02	0.31	0.01	0.03	0.09	0.46
		3	0.51	0.01	1.45	0.15	0.03	0.03	0.18	0.42
BIOCLIM	ALL	1	0.53	0.04	0.70	0.48	0.06	0.00	0.63	0.26
		2	0.57	0.04	1.72	0.08	0.14	0.01	1.71	0.04
		3	0.57	0.04	1.76	0.07	0.14	0.01	1.60	0.05
	D&A	1	0.56	0.03	1.98	0.048	0.14	0.01	1.28	0.10
		2	0.55	0.03	1.78	0.07	0.11	0.01	1.01	0.15
		3	0.59	0.02	3.49	0.0005	0.17	0.01	1.41	0.08
	EL	1	0.55	0.03	1.72	0.08	0.10	0.01	0.81	0.21
		2	0.55	0.03	1.69	0.09	0.10	0.01	0.83	0.20
		3	0.53	0.02	1.47	0.14	0.06	0.2	0.39	0.34

1 Models, 2 Environmental factors, 3 Repetition, 4 Area under the ROC curve estimates if the prediction is significantly different as by chance (AUC ≤0.5), 5 Standard Error, 6 *z* statistic, 7 *p* probability indicating the significance difference from the critical AUC = 0.5, 8 Kappa statistic assesses the extend to which the model predicts by at a rate higher than by chance (0= no agreement to 1 = full agreement), 9 Kappa variance, 10 z-statistic for Kappa, *p* probability for Kappa, 12 All ten environmental factors, 13 only annual average dew point and temperature, 14 only elevation.

Table 26: Model accuracy for quality AAA predictions

Predictions were conducted with varying predictor combinations and evaluated by ROC AUC and Kappa indicators.

M[1]	EF[2]	R[3]	AUC[4]	SE[5]	*z*[6]	*p*[7]	K[8]	V[9]	z[10]	P[11]
MAXENT	ALL[12]	1	0.76	0.05	5.17	<0.0001	0.36	0.01	3.81	0.00006
		2	0.75	0.05	4.65	<0.0001	0.39	0.01	4.08	0.00002
		3	0.64	0.06	2.46	0.01	0.13	0.01	1.26	0.10
	D&A[13]	1	0.31	0.07	-2.57	0.01	0.35	0.01	3.55	0.00018
		2	0.79	0.04	6.58	<0.0001	0.43	0.01	4.63	<0.00001
		3	0.67	0.06	3.06	0.002	0.21	0.01	2.13	0.01
	EL[14]	1	0.68	0.06	3.23	0.001	0.32	0.01	3.31	0.0004
		2	0.76	0.05	1.28	0.20	0.46	0.01	4.92	<0.00001
		3	0.69	0.05	3.41	0.0006	0.36	0.01	3.81	0.00006
CaNaSTA	ALL	1	0.76	0.05	5.11	<0.0001	0.39	0.01	4.08	0.00002
		2	0.81	0.04	7.30	<0.0001	0.43	0.01	4.63	<0.00001
		3	0.69	0.06	3.39	0.0007	0.30	0.01	3.06	0.001
	D&A	1	0.81	0.06	5.18	<0.0001	0.39	0.01	4.08	0.00002
		2	0.82	0.04	7.45	<0.0001	0.50	0.01	5.53	<0.00001
		3	0.75	0.05	5.09	<0.0001	0.36	0.01	3.81	0.00006
	EL	1	0.76	0.05	5.31	<0.0001	0.34	0.01	3.55	0.0002
		2	0.82	0.04	7.37	<0.0001	0.46	0.01	4.92	<0.00001
		3	0.72	0.05	4.29	<0.0001	0.39	0.01	4.08	0.00002
DOMAIN	ALL	1	0.59	0.04	1.93	0.05	0.17	0.01	1.42	0.07
		2	0.64	0.04	3.75	0.0002	0.28	0.01	2.31	0.01
		3	0.55	0.04	1.21	0.22	0.11	0.02	0.84	0.20
	D&A	1	0.48	0.03	-0.57	0.57	0.11	0.03	0.63	0.26
		2	0.56	0.02	2.61	0.009	0.13	0.03	0.79	0.21
		3	0.54	0.02	2.12	0.03	0.08	0.03	0.49	0.31
	EL	1	0.51	0.01	1.01	0.30	0.02	0.04	0.11	0.46
		2	0.54	0.02	2.07	0.04	0.09	0.03	0.48	0.31
		3	0.53	0.02	1.81	0.07	0.06	0.03	0.35	0.36
BIOCLIM	ALL	1	0.63	0.05	2.69	0.007	0.26	0.01	2.51	0.006
		2	0.62	0.05	-1.59	0.11	0.23	0.01	2.27	0.01
		3	0.54	0.05	0.84	0.40	0.09	0.01	0.80	0.21
	D&A	1	0.50	0.05	0.00	1.00	0.04	0.03	0.26	0.39
		2	0.61	0.04	3.21	0.001	0.22	0.02	1.83	0.03
		3	0.53	0.03	1.03	0.30	0.06	0.03	0.39	0.34
	EL	1	0.56	0.03	1.94	0.05	0.13	0.02	0.86	0.19
		2	0.56	0.02	2.58	0.01	0.13	0.03	0.78	0.21
		3	0.52	0.02	0.84	0.40	0.04	0.032	0.24	0.40

1 Models, 2 Environmental factors, 3 Repetition, 4 Area under the ROC curve estimates if the prediction is significantly different as by chance (AUC ≤0.5), 5 Standard Error, 6 *z* statistic, 7 *p* probability indicating the significance difference from the critical AUC = 0.5, 8 Kappa statistic assesses the extend to which the model predicts by at a rate higher than by chance (0= no agreement to 1 = full agreement), 9 Kappa variance, 10 z-statistic for Kappa, *p* probability for Kappa, 12 All ten environmental factors, 13 only Annual average dew point and temperature, 14 only elevation.

The McNemar test was used to show the statistical difference between the models, the test is like a Kappa test but is designed to compare models. CaNaSTA is statistically significantly the most suitable model for the prediction of qualities A and AA using all input variables, for quality AAA CaNaSTA is also statistically significantly better than Domain and BioClim but not as MaxEnt. The remaining models are not statistically distinguishable (Table 27).

Table 27: McNemar model comparison using all input variables

Quality.	Models	MaxEnt	CaNaSTA	Domain
A	CaNaSTA	SD[1]		
	Domain	0.32	SD	
	BioClim	0.81	SD	0.56
AA	CaNaSTA	SD		
	Domain	0.59	SD	
	BioClim	0.41	0.09	0.23
AAA	CaNaSTA	0.23		
	Domain	0.15	SD	
	BioClim	0.14	SD	1

[1] Statistically significant different

For average annual temperature and average annual dew point only CaNaSTA was the statistically significant most suitable model for A and AAA quality prediction (Table 28). For quality AA CaNaSTA is better than Domain but not statistically different form BioClim and MaxEnt. For quality A, BioClim is more suitable than MaxEnt. For quality AA, BioClim is more suitable than Domain. For quality AAA MaxEnt is significantly more suitable than either Domain or BioClim, which are not distinguishable one from the other. In summary is CaNaSTA the most suitable model followed by MaxEnt, BioClim and finally Domain.

Table 28: McNemar model comparison using selected input variables
Average annual temperature and average annual dew point were used as predictor variables.

	Models	MaxEnt	CaNaSTA	Domain
A	CaNaSTA	SD[1]		
	Domain	0.08	SD	
	BioClim	SD	SD	1
AA	CaNaSTA	0.50		
	Domain	0.21	SD	
	BioClim	0.26	0.93	SD
AAA	CaNaSTA	SD		
	Domain	SD	SD	
	BioClim	SD	SD	1

[1] Statistically significant different

When using only elevation data as the input variable, CaNaSTA is significantly more suitable than either Domain and BioClim for qualities A, AA and AAA, except for BioClim with quality AA (Table 29). CaNaSTA is only significantly more suitable than MaxEnt for quality A. On the other hand MaxEnt is also significantly more suitable than Domain and BioClim for quality AAA. BioClim is more suitable for quality A than MaxEnt. For these data, CaNaSTA is the most suitable model followed by MaxEnt; while Domain and BioClim are not distinguishable one from the other.

Table 29: McNemar model comparison using elevation as predictor variable

	Models	MAXENT	CaNaSTA	DOMAIN
A	CaNaSTA	SD[1]		
	DOMAIN	0.09	SD	
	BIOCLIM	SD	SD	0.12
AA	CaNaSTA	0.07		
	DOMAIN	0.83	SD	
	BIOCLIM	0.47	0.17	0.05
AAA	CaNaSTA	0.62		
	DOMAIN	SD	SD	
	BIOCLIM	SD	SD	0.21

[1] Statistically significant different

The model comparison shows that CaNaSTA is for all the different conditions the most suitable model; the differences are not always significant. CaNaSTA is followed by Maxent. Bioclim is only in some instances more suitable than Domain.

6.2.2 Data threshold

According to the model comparison, CaNaSTA is the most suitable model for prediction of specialty coffees. A case study to validate CaNaSTA and determine the data threshold was therefore conducted, using data from El Tambo-Timbio and Inzá and the pooled data set using different data thresholds. The prediction and evidence quality scores were compared, with the hypotheses being:

H_0 = Prediction and evidence scores are independent (null hypothesis)

H_1 = Prediction and evidence scores are dependent

In El Tambo-Timbio the P-value decreases from 0.062 to 0.019 with increasing numbers of prediction points (Table 30). With the 25/75 set, the null hypothesis is accepted, that is the prediction and evidence scores are independent. For the 50/50 and 75/25 sets, H_1 can be accepted with P=0.052, that is the prediction and evidence scores are dependent. In Inzá the null hypothesis is accepted with P=0.014 for the 75/25 set, for the 50/50 set with P=0.081 it is just rejected and for the 25/75 it is clearly rejected. When analyzing the entire area no pattern is distinguishable, 50 and 75 percent of the data points predict the niches at P=0.056 and 0.13 respectively, which are reasonable

P-values, remembering that the CaNaSTA methodology uses site data combined with the relevant environmental data to predict areas that are suitable to produce specialty quality coffee. This implies that predictive relationships derived for Inzá is used to predict qualities in El Tambo-Timbio and vice versa. It is also obvious that the niches cannot be identified with a high degree of confidence, but the methodology still serves for a general delimitation of niches that can thereafter be refined by concentrating the analysis window at the niche scale, in other words by using a smaller window to define the niche more closely.

Table 30: Area, number of samples and P values of the likelihood ratio chi-square
The analyses were run for the entire area and for the two niches

	Area	**n**	**25 / 75**	**50 / 50**	**75 / 25**
Cauca	775,866 ha	88	0.43	0.056	0.13
El Tambo-Timbio	160,765 ha	48	0.062	0.051	0.019
Inzá	16,005 ha	27	0.86	0.081	0.014

6.3 Specialty coffee quality prediction

The previous analyses proved the validity of CaNaSTA predictions. In this section a case study is presented predicting high quality coffee niches for the Cauca department.

6.3.1 Niche identification

A niche identification was run in CaNaSTA using the entire data set (88 sampled sites) and the ten environmental evidence factors. The range of qualities was divided into five ranges of final scores: < 70, 70 - 75, 75 - 80, 80 - 85 and > 85. The maps in figures 26 and 27 show the probability of producing a specific final score according to the natural environment where coffee is grown in Cauca department. It is obvious that it is easier to reach a final score of 75 to 80 than one above 85. As the final score increases, the area suitable for growing the coffee decreases. The conclusion is that only small areas comply with the requirements to produce high final scores. Nevertheless, ecological niches can be identified with high probabilities of producing an excellent coffee. Figure 28 shows the most probable quality per niche. It is a summary analysis that shows again that large areas produce mediocre coffee but only very limited areas can produce superior quality coffee. The same effect of niches can be observed in

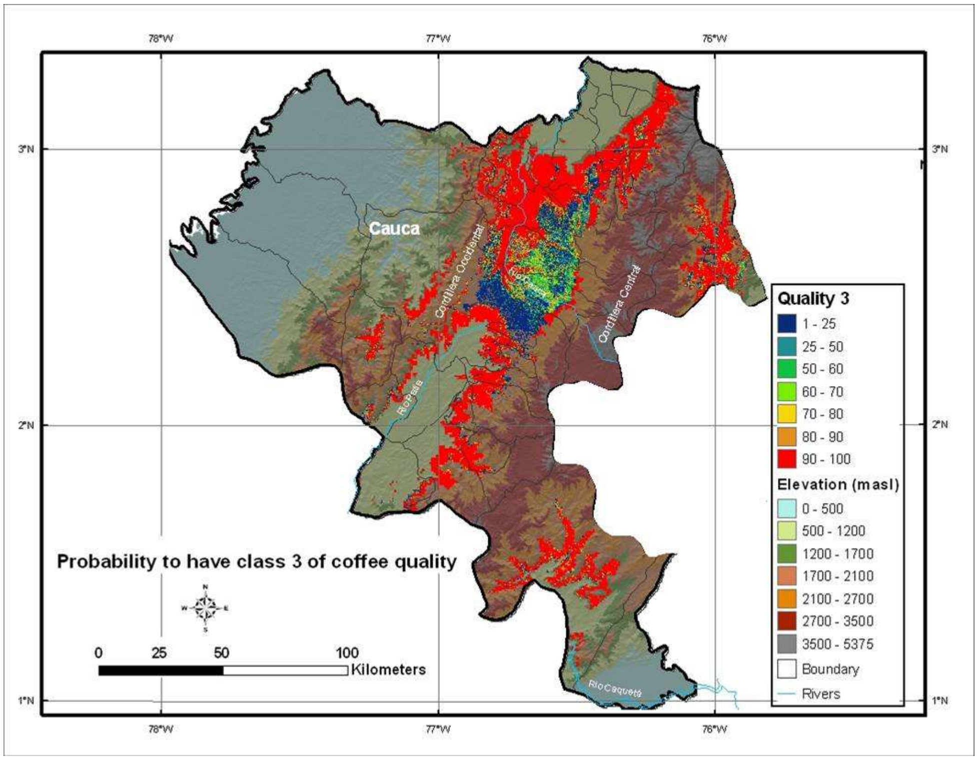


Figure 26: Probability of producing coffee with a final score between 75 and 80.

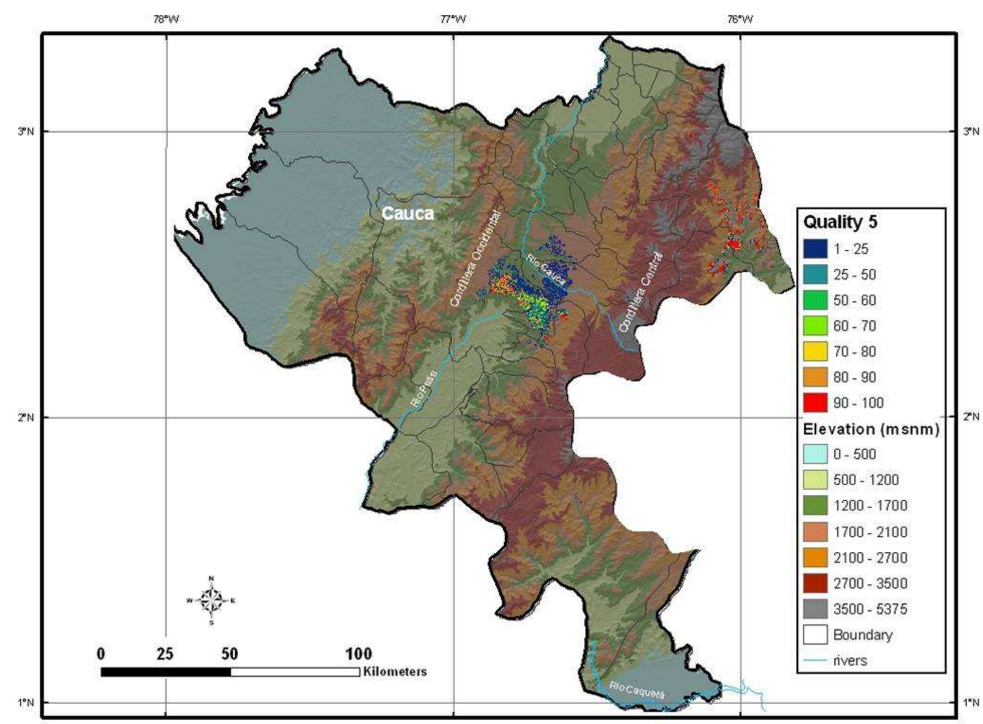


Figure 27: Probability of producing coffee with a final score above 85.

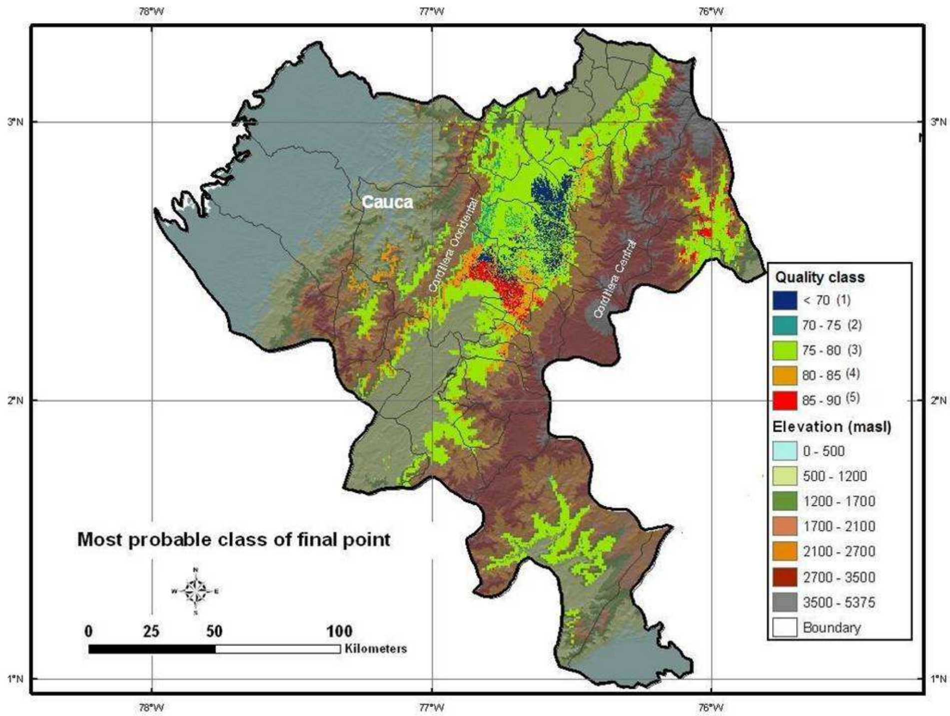


Figure 28: Most likely quality class that can be produced.

maps generated for individual organoleptic characteristics such as acidity, sweetness, and body (results not presented). The niches identified are the municipalities of El Tambo-Timbio in the Popayan area and the municipality of Inzá on the eastern border of the Cauca department.

6.3.2 Niche characterization

It has been shown that there are two niches apt to produce high quality coffees, the niche of El Tambo-Timbio and Inzá. The two niches are very distinct in terms of climate and geomorphology as discussed in chapter four, which means that there is not just one suitable environment for the production of quality coffee. To illustrate the site specificity of the interactions of environmental factors with quality, a "driving factor" analysis was run for the entire data set and for the two niches separately (Tables 31 and 32). For the entire data set, only one enhancing and three reducing factors were identified having a significance value (c) > 2. As stated previously, by running a general analysis, areas that produce high-quality coffee can be predicted based on evidence data from distinct environmental conditions and insights into the interactions with coffee quality, which are only of a general nature. When analyzing niche by niche, a more detailed set of responsible factors can be obtained.

Table 31: Quality enhancing factors impacting on the final score
Attributes of the niches Inzá, El Tambo-Timbio and the whole Cauca sampling area are presented. The significance indicator *c* is shown in parentheses

Quality enhancing factors	Entire data Set	Inzá	El Tambo-Timbio
Altitude (masl)		1750 -1800 (2.02)	1652 -1725 (2.32)
			1725 -1798 (2.39)
Average annual dew point (°C)		11.9-12.2 (2.43)	
		12.3-12.6 (2.07)	12.3 – 12.8 (2.38)
Average annual temperature (°C)		17.7 -18.1 (2.55)	17.8-18.9 (2.32)
		18 -18.4 (2.21)	
Average annual precipitation (mm)		1645 -1674 (2.2)	
	1760 – 1934 (2.31)	1587 -1616 (2.1)	

Table 32: Quality reducing factors impacting on the final score
Attributes of the niches Inzá, El Tambo-Timbio and the whole Cauca sampling area are presented. The significance indicator *c* is shown in parentheses

Quality reducing factors	Entire data set	Inzá	El Tambo-Timbio
Altitude (masl)	1528 – 1623 (2.74)		
Slope (degrees)			34.5 – 40.9 (2.55)
		22.4 -25.6 (2.54)	21.6 – 27.9 (2.10)
Average annual dew point (°C)	12.8 – 13.5 (2.4)	11.5 -11.9 (2.57)	14.3 -14.8 (2.00)
Average annual temperature (°C)		17.3 – 17.7 (2.47)	20 - 21 (2.02)
Average annual solar radiation (Mj/m2/d)			21.8 – 22.3 (2.32)
Average annual precipitation (mm)	1133 – 1587 (2.78)		
Dry month per year (mth / yr)		3 (2.81)	

For both niches, altitude, average annual temperature and average annual dew point enhance final quality score. The ranges are only slightly different between the two Cauca sites, Inzá having lower temperatures and higher altitudes than El Tambo-Timbio. Average annual precipitation is an important enhancing factor in Inzá and for the entire Cauca data set. In contrast, slope influences final score negatively in both niches. Dew point above and below the range identified as enhancing quality have a negative impact as does average annual temperature. The optimal annual average temperature in Inzá is 17.7 – 18.4°C but is slightly higher (17.8 – 18.9°C) for El

Tambo-Timbio. The results demonstrate variability in the environmental factors that impact on final score and the need to assess these factors according to their niches. The findings also prove that there are different environmental niches apt to produce high quality coffee and that the environmental factors, their combination and weighting are distinct from on niche to another.

6.4 Discussion

6.4.1 Is environmental niche identification viable?

The comparison and evaluation of models demonstrates that CaNaSTA predicts qualities best. According to two independent tests, the predictions in the majority of cases are statistically significantly better than by chance. Depending on the input data and the evaluation indicator, the predictions range from moderate to excellent. Taking into account that the data from Honduras were not processed in a standardized manner and may well include noise caused by sub-optimal farm management and post-harvest processing, the CaNaSTA predictions are very precise. CaNaSTA has been validated and predicts quality accurately for small niches and satisfactorily for larger regions. The CaNaSTA quality predictions are a viable option to determine the comparative advantage of farmers' natural environments and are significantly better than random predictions. CaNaSTA allows associations and national institutions to reduce uncertainty and minimize risk for local and regional decision makers. The information generated indicate where farmers have high potentials to participate in the specialty coffee sector, where coffee production should focus on main-stream coffees and where alternative crops for conversion or difersification have to be identified.

6.4.2 Is the information novel?

CaNaSTA infers the unknown quality of coffees based on the state of known attributes under the assumption that coffee qualities are dependent on these attributes. The approach is novel because only a very limited number of data points are necessary in order to identify qualities over a large area. In the past, controlled experiments were conducted that allowed predictions to be made for only very restricted areas. The commercial data used in the analyses reported here assures that the results are from real world conditions. In contrast, controlled experiments do not always reproduce the conditions of farmers' fields.

6.4.3 Can environmental niche identification generally be applied?

The niche prediction has been tested also in Veracruz, Mexico and compared using different, approaches (Martinez et al., 2006) and showed promising results. What is the practical use of niche identification and how can this information be used by farmers and associations? A spin-off the research reported here is a denomination of origin study for Colombia that uses as part of the basis for delimiting *terroir* the spatial analyses tools presented here. The tool is also being tested to predict areas where pest and disease management has to focus or where it is not of such importance. This research will be part of integrated pest and disease management.

6.4.4 Can the information be delivered?

The models are not straight forward; analyses have to be conducted by trained personal and can thereafter be disseminated or built-in decision or policies. The data of the present research had been managed in the Cinfo system (Oberthür et al., 2006), an online data base. Cinfo is currently being investigated to see if decision support tools could be incorporated into it that would allow periodicity analyses and visualization of the data stored in it. The quality predictions could be consulted by the various actors in the coffee supply chain. With every new harvest cycle and associated cupping data the maps would become more precise. To date Cinfo already permits the visualization of individual farms and the quality of the coffee they produce on a mapping environment based on Google Earth

6.5 Conclusions

1. CaNaSTA is the most precise prediction model, MaxEnt the second while Domain and BioClim are not always distinguishable one from the other, but Bioclim is often more precise than Domain.

2. The performance of the models is best for indicating which environments produce high quality coffees and how the environments differ from those that produce lower qualities.

3. There is a slight improvement in precision with increasing evidence variables only in some instances in MaxEnt, which was not the case for CaNaSTA. This suggests the validity of the Paretto principle that few factors are responsible for the majority of causes.

4. Niches can be identified statistically significantly, for larger areas the predictions are less accurate but still satisfactory for a general identification and delimitation.

5. The environments of high quality niches differ from one site to another. The niches are composed of distinct combinations of factors that define coffee quality. The combination of factors and the weight of single factors varies from niche to niche.

6. CaNaSTA allows the identification of farmers' comparative environmental advantage.

7 SITE SPECIFIC FARM MANAGEMENT

Specific objective 4: To develop and test concepts of site specific agronomic and post-harvest management practices for improved coffee quality.

The objective of this chapter is to illustrate the process of how systematic targeting of farm management practices can be implemented by smallholder growers and their supply chain partners. The process of targeting management practices is illustrated with case studies using data from Colombia and Mexico. The study looked at some of the biophysical, agronomic and post-harvest management variables that influence coffee quality. The importance on coffee quality of aspect, slope position, choice of varieties, fruit thinning, harvest by level on the plant, harvest time, time lag between harvest and processing, status of post-harvest equipment, fermentation, and drying were examined. The chapter also appraises the conceptual frame work and the implications of these findings for small-scale coffee producers.

7.1 Descriptive statistics

7.1.1 On farm agronomic management trials

The farms chosen for this study are described in section 3.2.1. Briefly there were two estates greater than 25 ha in the municipalities of Concordia in Antioquia and Piendamo in Cauca, 33 small farms in Inzá, Cauca and two farms about 5 ha in El Encinal and Axocuapan in Mexico. The two Colombian estates have average values between seven and eight for the sensory characteristics of the coffee that they produce. Concordia tends to have higher values and also results that are less variable as indicated by the smaller ranges and lower standard deviation of the data. Concordia reaches an average final score of more than 80 points, which is remarkable. The highest final scores for the both estates were more than 90 points. The Inzá farms had relatively low values between three and six for the sensory characteristics, which was expected due to the different quality preferences of the cupping panel. The results indicate highly variable product quality coming from the 33 farms. The results from the two Mexican farms indicate that the quality of the coffee is very similar in both farms, although results from Axocuapan tend to be slightly more variable. Table 33 summarizes the results of the coffee beverage sensory analyses.

Table 33: Descriptive statistics for all sites
The results include the two Colombian estates (Concordia, Piendamo), the small farms of Inzá in Colombia and the two Mexican farms (El Encinal, Axocuapan). Samples for all biophysical variables and management practices are included in the analyses.

	Statistical indicators	Aroma Fragrance	Acidity	After-Taste	Body	Flavor	Sweet-ness	Prefer-ence	Final-score
Piendamo n=139	Minimum	4.00	5.00	3.75	7.00	4.00	6.00	4.00	59.75
	Mean	7.53	7.60	7.04	7.90	7.33	7.83	7.08	78.08
	Maximum	9.00	9.25	9.50	9.00	9.25	10.00	9.75	91.50
	Std devn	0.91	0.81	1.24	0.46	1.13	0.71	1.43	7.56
Concordia n=76	Minimum	5.00	6.25	5.00	6.00	6.00	5.00	6.00	63.50
	Mean	7.64	7.82	7.43	7.99	7.85	8.13	7.83	82.25
	Maximum	9.00	9.25	10.00	9.00	10.00	10.00	10.00	92.00
	Std devn	0.72	0.64	0.98	0.58	0.86	0.92	0.94	5.03
Inzá n=33	Minimum	2.00	3.00	4.00	3.00	4.00	2.00	3.00	39.00
	Mean	6.05	5.78	5.77	5.56	5.77	2.83	5.37	54.59
	Maximum	8.00	8.00	8.00	9.00	8.00	5.00	8.00	77.00
	Std devn	1.43	1.19	1.11	1.29	1.05	0.70	0.98	8.58
El Encinal n=97	Minimum	8.50	6.10	n.a. [1]	4.80	n.a.	n.a.	n.a.	n.a.
	Mean	9.73	8.27	n.a.	6.00	n.a.	n.a.	n.a.	n.a.
	Maximum	11.40	10.40	n.a.	7.20	n.a.	n.a.	n.a.	n.a.
	Std devn	0.58	0.89	n.a.	0.42	n.a.	n.a.	n.a.	n.a.
Axocuapan n=48	Minimum	8.20	6.70	n.a.	4.70	n.a.	n.a.	n.a.	n.a.
	Mean	9.52	8.81	n.a.	6.07	n.a.	n.a.	n.a.	n.a.
	Maximum	11.10	11.40	n.a.	7.00	n.a.	n.a.	n.a.	n.a.
	Std devn	0.58	1.09	n.a.	0.50	n.a.	n.a.	n.a.	n.a.

[1] na = not available

7.1.2 Pair sample comparison

In Inzá ,quality of producer and standardized samples is less variable than in El Tambo-Timbio, indicated by the lower standard deviation and the smaller ranges (Table 34). However the standard deviation of the differences between standardized and producer samples are higher in Inzá than in El Tambo-Timbio, which indicates higher variability due to post-harvest processing in Inzá. If average producer samples score higher than standardized samples, it is likely to be due to the smaller volumes that are processed using the standard method. In El Tambo-Timbio, the average time lag between harvest and processing is longer than in Inzá, while the opposite is true for the fermentation time (Table 34).

Table 34: Descriptive statistics for pair samples in Cauca

Pair samples	Statistical indicators	Time lag	Fermentation Time	Difference	Final score (P[1])	Final score (S[2])
All (44)	Minimum	4.0	10.0	-19.0	61.2	59.7
	Mean	8.3	14.0	3.4	78.9	75.5
	Maximum	12.0	24.0	26.0	88.7	89.5
	Std devn	1.8	3.0	11.3	6.6	8.4
El Tambo-Timbio (28)	Minimum	4.0	10.0	-19.0	61.2	59.7
	Mean	8.5	12.7	3.2	78.0	74.9
	Maximum	10	15	26.0	88.5	89.5
	Std devn	1.41	1.3	12.7	7.1	9.0
Inzá (16)	Minimum	4.0	12.0	-14.0	66.7	64.7
	Mean	7.9	16.2	3.9	80.6	76.7
	Maximum	12.0	24.0	16.0	88.7	88.7
	Std devn	2.3	3.7	8.5	5.5	7.4

[1]Producer and [2] standardized on farm samples

Coffee is mainly processed in the traditional way (Table 35), only three farmers in El Tambo-Timbio use BECOLSUB. The state of the equipment and the working environment is considered by the majority of producers to be sufficient to good; only one farmer in Inzá argued that improvement was needed. In El Tambo-Timbio coffee is mainly dried under direct sun on the floor and secondly under some kind of protection, while in Inzá the opposite is the case.

Table 35: Categorical data of the comparison study

Variable	Category	# ALL	# El Tambo-Timbio	# Inzá
Post-harvest practice	Traditional	37	21	16
	BECOLSUB	3	3	0
State of equipment and working environment	Good	13	7	6
	Sufficient	26	18	8
	Needs improvement	1	0	1
Drying type	Sun dried on the floor	15	12	3
	Mobile sun dryer	5	5	0
	Sun dried with protection	20	7	13
	Silo	2	2	0

7.1.3 On-farm post-harvest trials

The quality of the samples of the fermentation trial range from final score 60 to 83, with standard deviations from 4.1 to 7.5 (Table 36).

Table 36: Descriptive statistics of the fermentation experiment

	All Data	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
n	30	5	5	5	5	5	5
Minimum	60.0	66.5	66.2	64.4	68.0	68.0	60.0
Mean	73.7	73.7	75	76.9	75.0	74.6	68.9
Maximum	83.0	79.0	79.0	83.0	79.0	78.5	77.5
Std devn	6.1	4.8	6.7	7.5	4.5	4.1	7.9

Both batches of samples dried under the sun have higher average final scores than the ones dried in silos. The differences in quality of the May batch ranges from -4.2 to 15.6 and for the June batch from -2.4 to 16.5 (Table 37).

Table 37: Descriptive statistics of the drying experiment

	Batch May 06			Batch June 06		
	Sun	Silo	Difference	Sun	Silo	Difference
n[1]	9	9	9 pairs	6	6	6 pairs
Minimum	74.7	69.0	-4.2	76.4	68.1	-2.4
Mean	80.5	76.6	3.9	82.3	73.3	9.1
Maximum	87.5	88.5	15.6	84.6	78.8	16.5
Std devn	4.3	7.0	6.4	3.2	3.8	6.7

[1] Each of the nine or six samples is the average of 2-4 replications.

7.2 Impact of farm management on sensorial quality

7.2.1 Biophysical factors

On the Concordia estate the best quality coffee comes from south-facing slopes with a final score of 83.9. Berries harvested from the plateau also achieve very good results with a final score of 83.4. The east-facing slopes have generally the lowest values albeit with a still acceptable final score of 80.8 (Table 38). The situation presents itself very different in the Piendamo estate where east-facing slopes score second best after the plateau site. South-facing slopes perform badly compared with all other aspects and achieve final score of only 72.8. This represents an astounding difference of almost eight points between the best- and the worst-performing site. As noted above, farmers believe that the lower slope positions are more fertile than the upper slopes.

Table 38: Effects of aspect and position in the slope on coffee beverage quality

Samples included are from the Concordia and Piendamo estates based on one-way ANOVA and t-test. Data for the same attribute followed by the same letter are not significantly different according to Duncan's multiple range test (P<0.05, aspect) and t-test (P<0.05, slope position).

Aspect	**Aroma Fragrance**	**Acidity**	**After-Taste**	**Body**	**Flavor**	**Sweet-ness**	**Prefer-ence**	**Final-score**
				Aspect Concordia estate ANOVA				
North	7.83 a	7.81 a	7.10 b	7.94 a	7.81 ab	8.16 a	7.75 a	82.06 a
East	7.57 a	7.62 a	7.27 ab	7.57 a	7.45 b	7.81 a	7.60 a	80.76 a
South	7.42 a	7.94 a	7.93 a	7.94 a	8.25 a	8.40 a	8.18 a	83.85 a
West	7.79 a	7.29 a	7.22 ab	8.08 a	7.91 ab	8.25 a	7.88 a	81.95 a
Flat	7.67 a	8.12 a	7.67 ab	7.92 a	7.97 ab	8.05 a	7.70 a	83.42 a
				Aspect Piendamo estate ANOVA				
Northwest	7.28 b	7.73 a	7.31 a	7.86 a	7.55 a	7.75 a	7.30 a	79.77 a
East	7.50 ab	7.78 a	7.66 a	7.93 a	7.66 a	8.12 a	7.47 a	80.62 a
South	7.15 b	6.89 b	6.00 b	7.54 a	6.45 b	6.99 b	6.33 b	72.80 b
West	7.57 ab	7.41 ab	6.88 a	7.83 a	7.37 a	7.62 ab	7.30 a	78.00 ab
Flat	7.54 ab	7.88 a	7.36 a	7.98 a	7.69 a	8.05 a	7.41 a	80.67 a
				Slope position Concordia estate T-test				
High	7.63 a	7.70 a	7.52 a	7.90 a	7.79 a	8.22 a	7.85 a	82.40 a
Low	7.63 a	7.62 a	7.28 a	7.86 a	7.86 a	8.07 a	7.84 a	81.83 a
				Slope position Piendamo estate T-test				
High	7.45 a	7.69 a	7.09 a	7.50 b	7.41 a	7.83 a	7.22 a	79.66 a
Low	7.31 b	7.26 a	6.93 a	8.07 a	7.18 a	7.45 a	7.05 a	76.29 a

Coffee quality was indeed influenced by slope position with the higher slope positions generally performing better in coffee-quality characteristics. Once again, the differences were greater on the Piendamo estate; with a difference of three points in the final score compared with the Concordia estate with less than one point difference. In Concordia only flavor appears to be better in coffee harvested in the lower slope positions. In Piendamo only body was perceived better in berries harvested in lower slope positions. It is not clear how fertility differences could bring about these differences.

Aspect and some slope values in the Piendamo estate were considerably greater than for Concordia estate, or, in other words, slope and aspect are important at Piendamo in Cauca but are only slightly important at Concordia in Antioquia. It is not clear why this should be as the altitudes and rainfall differ only slightly and coffee is grown without shade on both estates. Clearly the interactions between aspect and quality are more subtle than might be expected.

7.2.2 Variety

Quality characteristics differed between varieties in the two Mexican sites. In El Encinal, the Red Caturra variety had highest values for fragrance/aroma and acidity, followed by Mundo Novo for both characteristics. Only when body is considered do Typica and Yellow Caturra achieve higher values (Table 39). In Axocuapan, Typica performed best for fragrance/aroma and for body and Red Caturra gave the highest values for acidity.

Table 39: Effect of variety on beverage quality

Data included are from the El Encinal and Axocuapan farms in Mexico, based on one-way ANOVA (El Encinal) and t-test (Axouapan). Data for the same attribute followed by the same letter are not significantly different (P<0.05 t-test or Duncan's multiple range test for ANOVA)

Variety	**Aroma Fragrance**	**Acidity**	**After-Taste**	**Bod y**	**Flavor**	**Sweet-ness**	**Prefer -ence**	**Final-score**
			Varieties El Encinal ANOVA					
Typica	9.45 a	8.03 a	n.a.	6.1 a	n.a.	n.a.	n.a.	n.a.
Red Caturra	10.17 b	9.02 b	n.a.	5.9 a	n.a.	n.a.	n.a.	n.a.
Mundo Novo	9.78 ab	8.22 a	n.a.	5.9 a	n.a.	n.a.	n.a.	n.a.
Yellow Caturra	9.57 a	7.80 a	n.a.	6.0 a	n.a.	n.a.	n.a.	n.a.
			Varieties Axocuapan T-test					
Typica	9.81 b	8.70 a	n.a.	6.2 b	n.a.	n.a.	n.a.	n.a.
Red Caturra	9.22 a	8.95 a	n.a.	5.8 a	n.a.	n.a.	n.a.	n.a.

7.2.3 Shade management

To understand the impact of different shade management on coffee-quality characteristics, sites were grouped into two classes, one with relatively high-shade coverage and one with relatively low-shade coverage. At Inzá, the mean shade level of the 17 sites in the low-shade class was 37%. The fifteen sites with denser shade averaged of 61 % (Table 40). Shade coverage ranged from 26 % to 49 % and from 52% to 79% in the low- and high- shade classes respectively (data not presented in tabular format). The coffees brewed from berries that were harvested under denser shade generally scored higher than coffees derived from berries grown under lower shade levels. These differences are consistent for all quality characteristics, except sweetness, albeit only statistically significant for body. The individual characteristics result in final scores of 53.2 for lower shade density and 56.3 for the higher shade class, a difference of a little over three points.

Table 40: Effect of shade level on beverage quality
The data included is of samples from in Inzá, El Encinal and Axocuapan. Data for the same attribute followed by the same letter are not significantly different (P<0.05, t-test).

Shade descriptor (%)	Aroma Fragrance	Acidity	After-Taste	Body	Flavor	Sweet-ness	Prefer-ence	Final-score
Average shade levels (%) in Inzá, T-test								
36.5	5.89 a	5.55 a	5.50 a	5.13 b	5.41 a	2.97 a	5.18 a	53.16 a
60.6	6.18 a	6.06 a	6.07 a	6.06 a	6.21 a	2.67 a	5.21 a	56.30 a
Average shade levels (%) in El Encinal, T-test								
68.2	9.79 a	8.36 a	n.a.	6.1 a	n.a.	n.a.	n.a.	n.a.
87.0	9.68 a	8.19 a	n.a.	5.9 b	n.a.	n.a.	n.a.	n.a.
Average shade levels (%) in Axocuapan, T-test								
68.2	9.68 a	8.96 a	n.a.	6.2 a	n.a.	n.a.	n.a.	n.a.
87.0	9.39 a	8.96 a	n.a.	5.9 b	n.a.	n.a.	n.a.	n.a.

Consistent differences were also found in Mexico. Shade density on average was much higher in Mexico. In both communities the lower-density shade group had an average of 68.2% coverage and the more densely shaded areas had an average of 87%. Contrary to the results from the Inzá farms in Colombia, beverages prepared from berries harvested under less shade performed better in Mexico than their dense-shade counterparts. Differences are, however, not statistically significant at the P<0.05 level.
Average direct and diffuse photosynthetically active radiation flux density measured under the shade canopy (PPFDU) during the growing season was 9.10 µmol m^{-2} s^{-1} in Inzá. A correlation analyses illustrated that PPFDU was negatively correlated with all quality attributes except for fragrance/aroma. The correlation coefficients for aroma/fragrance, acidity, aftertaste, body, flavor, sweetness, preference and the final score were 0.05, -0.25, -0.44, -0.47, -0.44, 0.12, -0.32 and -0.18 respectively.

7.2.4 Harvest management

Three different harvest management practices were considered in the two estates in Colombia including manual fruit thinning, different harvest date and harvest from different coffee tree canopy levels (Table 41).

Table 41: Effect of management practices on bewerage quality

Data include fruit thinning (samples from estates in Concordia and Piendamo), harvest time (samples from Piendamo estate) and harvest in different canopy levels (samples from Concordia estate) on beverage quality. Data for the same attribute followed by the same letter are not significantly different (P<0.05 t-test or Duncan multiple range test for the ANOVA analyses).

Treatments	**Aroma Fragrance**	**Acidity**	**After-Taste**	**Body**	**Flavor**	**Sweet-ness**	**Prefer-ence**	**Final-score**
Fruit thinning (%) in the Concordia estate, T-test								
0	7.76 a	7.94 a	7.91 a	8.06 a	8.20 a	8.50 a	8.50 a	84.75 a
50	7.72 a	7.71 a	7.33 b	7.33 a	7.72 a	8.15 a	8.12 a	81.79 b
Fruit thinning (%) in the Piendamo estate, T-test								
0	7.32 b	7.37 b	6.99 a	7.75 a	7.25 a	7.68 a	7.15 a	77.79 a
50	7.62 a	7.71 a	7.14 a	7.89 a	7.52 a	7.70 a	7.27 a	79.18 a
Harvest time in the Piendamo estate, T-test								
May 12	7.47 a	7.72 a	7.27 a	7.86 a	7.53 a	7.25 a	7.89 a	79.79 a
June 09	7.83 a	7.51 b	6.88 b	7.83 a	7.17 b	6.95 a	7.69 b	77.52 b
Canopy level harvest in the Concordia estate, ANOVA								
Low	7.29 a	7.81 a	7.72 a	7.97 a	7.89 a	7.83 a	8.31 a	82.81 a
Medium	7.67 a	7.96 a	7.14 a	8.05 a	8.01 a	7.57 a	7.96 a	81.67 a
High	7.65 a	7.21 a	7.07 a	8.10 a	7.48 a	7.75 a	7.73 a	80.37 a

Fruit thinning by 50% resulted in consistently higher values for all quality characteristics in the Piendamo estate, giving final scores of 79.2 points for coffee from trees where the fruit load was reduced compared to 77.8 points from trees with full fruit load. In the Concordia estate differences were also found, but the better-scoring coffees were from berries harvested from trees that had no manual fruit thinning. The final scores in Concordia for the reduced and full fruit load were 81.8 and 84.8 points respectively, a difference of three points.

Early harvest (May 12) was generally more favorable than late harvest (June 09) for the coffee-quality characteristics apart from aroma/fragrance. Final scores for early and late harvested coffees were 79.8 points and 77.5 pints respectively, a difference of a little over two points.

Harvesting from different canopy levels in the Concordia estate also produced differences in beverage quality. Berries from the lower levels had the highest final score for the beverage. However the differences were not consistent with different coffee-quality characteristics giving the highest scores for different canopy harvest levels. For example, body was best in coffees brewed from berries that were harvested in the higher-level canopy but acidity and flavor were best from coffees brewed using berries from the middle-level canopy.

7.2.5 Post-harvest practices

To assess the impact of farmers' post-harvest processing, pair samples were compared, one sample was processed by the farmer and its pair by the standardized method. The producer samples scored statistically significant (p = 0.03) higher than the standardized-process samples (Figure 29). The difference between the pair sample (final score value of producer minus final score value of standardized sample) was used to quantify the impact of farmer's post-harvest processes on the brew quality. If the value is positive the producer post-harvest process was more successful than the standardized process and vice versa.

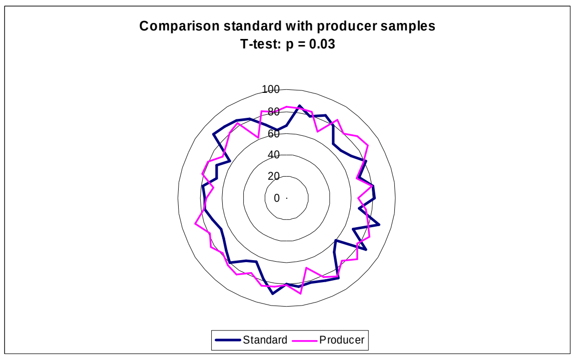


Figure 29: Final score difference between standardized and producer samples.
The producer samples score statistical significantly higher than the standardized samples.

Farmers responses about the state of their equipment and working environment were negatively correlated to the pair quality difference in El Tambo-Timbio (r = - 0.35) and in Inzá (r = - 0.21) (Figure 30). For farmers in El Tambo-Timbio the pattern was stronger than for farmers in Inzá.

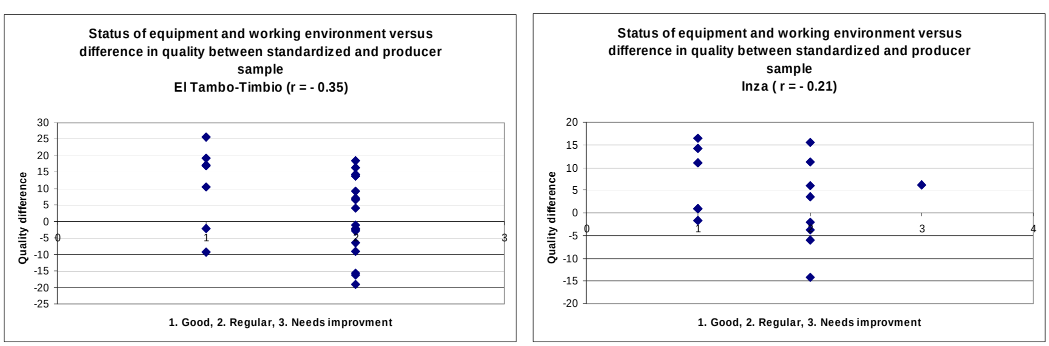


Figure 30: Correlation of quality difference to production environment.

The time lag between harvest and processing of the berries was negatively correlated to the quality difference (Figure 31). The correlations were higher in El Tambo-Timbio (r = - 0.29) than in Inzá (r = - 0.18).

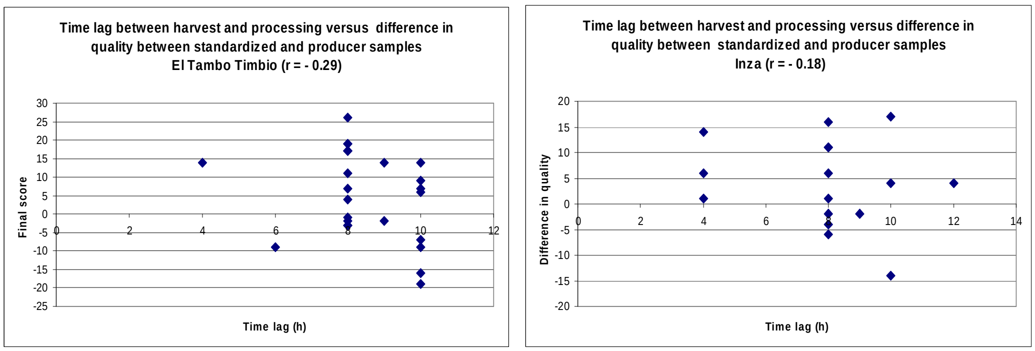


Figure 31: Correlation of quality difference to time

The number of hours farmers in El Tambo-Timbio and Inzá ferment ranges from eight to twenty-four hours (Figure 32). The fermentation time is highly correlated to the elevation of the farms (r = 0.51).

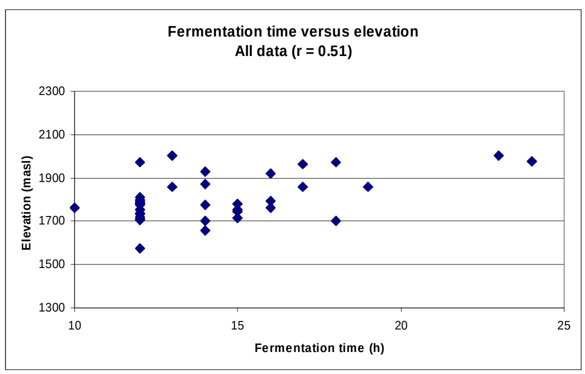
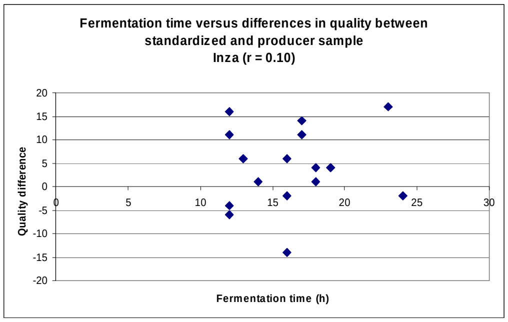


Figure 32: Fermentation time versus elevation.

The results of the pair sample comparison show that the fermentation time had very low correlation with the pair differences. For Inzá the correlation coefficient is r = 0.10 and in El Tambo-Timbio r = -0.06 (Figure 33).



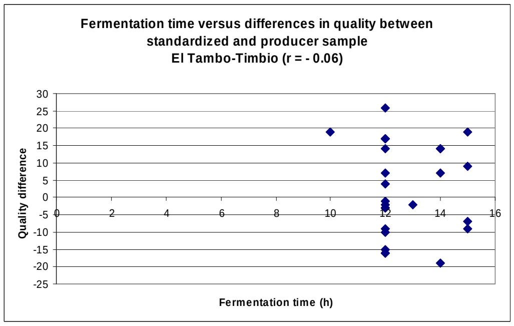


Figure 33: Correlation of quality difference with fermentation time.

The standardized samples had all been processed by a mobile post-harvest process unit (BECOLSUB). In addition to the de-pulping and removal of mucilage, the coffee was fermented for 5 hours to make sure that all the mucilage had been removed. Before processing the samples for the investigation, an on farm trial was conducted to estimate the appropriate fermentation time (Figure 34). The results show that on average the quality increases until the fifth hour and from there to the tenth hour it increases only slightly. After discussions with farmers in the field and taking into account the logistics of the process it was decided to ferment the coffee only five hours and neglect the slight improvement of quality between the fifth and tenth hour. The presented data consist of six samples from different farms of the municipality of Inzá.

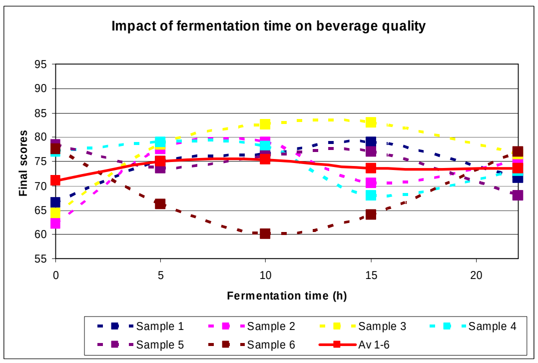


Figure 34: Optimal fermentation hours for the post-harvest processing unit.
Trail was conducted for fermentation hours after mucilage removal.

An on farm trial conducted in collaboration with the Piendamo estate shows that for the May and June harvest, sun drying gives higher quality scores than silo drying (Figure 35). The results are significantly increased in both occasions (May P = 0.05 and June P = 0.01).

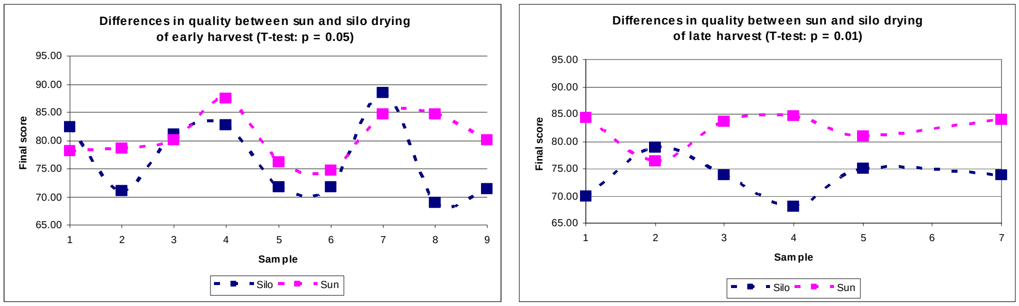


Figure 35: Differences in quality between sun and silo dried coffee beans.

7.3 Discussion

7.3.1 Is site specific farm management viable?

The case studies show that managing biophysical variables in coffee farms separately and the appropriate choice of agronomic practices can have impact on the attributes of coffee beverage quality. These differences are not consistent across sites and they are not always statistically significant. The impacts of the same biophysical variable and / or management practice can be negative at one site and positive in another site. The site-specific nature of the impacts is obvious.

While it provides helpful guidance, formal statistical tests of the significance of measured differences mean relatively little to growers in a commercial production situation. The information provided by growers' on-farm experimentation with biophysical variables and management practices has to be evaluated as to whether it generates commercial benefits. The cost-benefit ratio of generated information and the gains realized from decisions based on that information is the key yardstick for growers. In discussions with growers, the management implications were assessed in terms of resources (labor, yield, and quality evaluation), ease of implementation (knowledge and logistics), the potential for improvement of the beverage quality and the value added from the intervention (Table 42).

Table 42: Evaluation of management interventions

Evaluation was conducted by statistical significance, ease of implementation, likely improvement of quality, resource intensiveness, and added value.

Management	Statistical significance	Ease of implementation	Improvement of quality	Resource intensiveness	Added value[1]
Aspect	Medium	Easy	High	Low	High
Slope position	Low	Medium	Low	Medium	Low
Variety	Medium	Medium	Low-medium	High	Low-medium
Shade management	High	Easy	Medium	Medium	Medium
Fruit thinning	Medium	Difficult	Low-medium	High	Low-medium
Harvest time	High	Easy	Medium	Low	High
Harvest by canopy	Medium	Easy	Medium	Low	Low

[1] Cost-benefit ratio.

Aspect often has a statistically significant and consistent impact on beverage quality: in Concordia south-facing aspects scored the highest or second highest and in Piendamo south-facing aspects scored the lowest while east-facing aspects and flat sites scored the highest for the majority of quality attributes. The investment of harvesting sites with different aspects separately has only minor logistical implications and adds little to the cost of the production process. The quality differences due to aspect are remarkable considering that the sites were only a few hundred meters apart. Trees in upper slope positions score slightly higher than trees on lower position on the same slope, although the differences are not substantial in the data presented here.

Varieties have significant impacts on quality characteristics as shown in the Mexican sites El Encinal and in Axocuapan. However, to change varieties on a farm is resource-demanding and is not likely to be recommendable in many cases. Obviously, however, this is an option when farm renovation is being considered for other reasons. When a certain variety is identified that performs substantially better under specific environmental and management conditions there may be sufficient reason to recommend change of varieties. For example, the variety Geisha, which is not that traditionally grown in Panama, has been planted recently by a few growers. Intelligentsia Coffee Roasters in Chicago sells a half-pound of roasted Panamanian Hacienda La Esmeralda Geisha (a repeated competition winner) beans for US$52, an outstanding premium.

Shade management has been shown to have substantial impacts on quality on both the Colombian and the Mexican sites. Shade is easy and cheap to implement and a viable farm management practice not only for the improvement of coffee beverage quality but shade trees can also provide an additional source of income. Fruit thinning had a favorable influence on coffee beverage quality in the estate of Piendamo, but fruit thinning is not easy to implement and is labor intensive.

For the interpretation of the results, 80 points are usually considered the entry level to specialty coffees and coffees with more than 85 points can generate substantial premiums for growers. For example, during the 2006 Cup of Excellence® competition in Colombia (Cupofexcellence, 2006) the winning 23 farms had final scores ranging from 84.33 to 91.48 points. In the subsequent online auction, Maruyama Coffee for the Mikatajuku group, Stumptown Coffee Roasters and Intelligentsia Coffee Roasters Chicago bid US$12.05 per pound to secure the winning lot. Prices ranged from US$3.05 to US$12.05 respectively for a pound of these green coffees. For comparison, during 2006 the average price at the New York Board of Trade (NYBOT) for mild Colombian coffees was US$1.18 per pound of green coffee.

The Colombian estate coffees in this study were assessed by Mr. Geoff Watts of Intelligentsia Coffee Roasters Chicago. Watts is one of the leading international cuppers and specialty green coffee buyers. Intelligentsia uses their triple A pricing scheme where high quality coffees are rewarded AAA, intermediate specialty coffees AA and entry level specialty coffees A. The price premiums are US$1.35 for a pound of an A coffee with 80 to 84 points final score, US$1.55 per pound for an AA coffee with 85 to 87 points, and at least US$1.85 per pound for an AAA coffee with a final scores of 88 to 93 points. For boutique coffees of the highest quality Intelligentsia very often pays more than US$3 per pound of green coffee. An additional 35-40 cents per pound has to be added to Intelligentsia farm gate prices to obtain the FOB price.

If this scheme is applied, for example, to the results of the different slope aspects in the estate farms then this biophysical variable becomes commercially very interesting for separate management of fields with aspects that are likely to produce high-quality berries. The difference in the final score between the highest and lowest scoring aspect is 2.66 in the Concordia estate and 7.87 in the Piendamo estate. In Concordia the highest scores qualify as an AA premium. In Piendamo coffees from the south, east and northwest aspects can be sold as conventionally traded coffees at NYBOT prices while the eastern aspect coffees and the plateau coffees would qualify for an A premium.

Reducing the fruit load obviously reduces the yield level of coffee trees. Vaast *et al.* (2006) estimated for 50% reduction of flower buds gave an actual yield decrease of 25%. The best-performing sites reached an average green bean yield of 4.1 pounds per tree when flowering buds were reduced by 50%. The grower could therefore expect about US$4.84 per tree if sold at the NYBOT price. Considering an additional labor cost of 20 cents this translates into an actual loss of US$1.85 per tree when compared to the income of US$6.49 per tree without manual thinning. Sold at Intelligentsia with an A premium, the tree would generate US$5.34, with an AA premium US$6.16 and with an AAA premium US$7.39 income for the grower. On the rare occasion that a boutique coffee would be produced due to the thinning of flowering buds, the grower could expect a return of US$12.10 per tree. Positive effects from fruit thinning were also shown in Costa Rica, where reduced fruit load significantly improved preference and acidity score. Bitterness and astringency decreased with decreasing fruit load (Vaast *et al.* 2006). Fruit thinning allows a plant to concentrate energy in fewer fruits and permits an increased accumulation of carbon, sugar, acids and other components. As discussed in the literature review, fruit thinning has benefits for other species: kiwifruit (Smith *et al.* 1992), apples (Palmer *et al.* 1997), and peaches (Corelli-Grappadelli and Coston 1991, Souty *et al.* 1999).

Different harvest times also generate large quality differences, as shown here. Managing separately batches harvested at different times presents no logistical problems. Harvesting from different canopy levels may also be possible, although it requires very thorough briefing of the pickers and probably strict supervisory control during the harvest.

The adequate processing of high quality berries is crucial. Post-harvest processes are known to maintain or decrease but not to improve quality. The challenge is to target the processing to the site-specific conditions of the farm, which innovative on-farm trials and experimental design can help to do. The comparison of pair samples is an easily-implemented intervention that allows focusing on post-harvest processing variables. The higher scores of the farmers' own samples compared with the standardized samples is likely due to the relatively small samples of coffee berries that were processed in the standardized methodology compared to the farmers' samples. Chemical processes and biological activity differ between small and large samples. Although intriguing, this is unimportant because the objective was to process the standardized samples uniformly in order to have benchmark data to compare across sites. In chapter six, El Tambo-Timbio and Inzá were identified as high quality niches; however some farmers in these niches are not realizing their comparative advantage by producing coffee of only mediocre quality. Interestingly, farmers are aware of this, as is shown by their own perception of their post-harvest status, which is correlated to the final score quality of their coffees (r = - 0.35 in El Tambo-Timbio and r = -0.21 in Inzá).

The results further indicate that the time lag between harvest and processing is a more important problem in El Tambo-Timbio than in Inzá. If the analyses were run only with farmer-produced samples, the importance of delayed processing in Inzá would not have been detected. The correlations for El Tambo-Timbio were r = - 0.33 and for Inzá of r = -0.03 for farmer samples compared with r = 0.29 for El Tambo-Timbio and r = -0.18 for Inzá for standardized samples. Fermentation time and farm altitude is highly correlated (r = 0.51) in El Tambo-Timbio and Inzá when analyzed with producer samples only, though the pair sample comparison shows a weak correlation between the quality difference and the fermentation time. These findings imply that the farmers do a good job in targeting the fermentation time to their location.

The absolute final score is the response to the entire production process comprising variability introduced by the natural environment, agronomic management and post-harvest processes whereas the differences between standardized and producer sample only addresses the post-harvest environment. The importance of a benchmark comparison becomes evident in this context and demonstrates the novel approach to quality control to reduce variability. The innovation to identify the obstacles of realizing the comparative advantage lies in the correct choice of variables and design of the investigation.

7.3.2 Is the information novel?

The novelty of this concept is the participatory approach, the innovative experimental design and the use of commercial data. Farmers, together with researchers, defined the weak points in their process; innovative experiments were then designed and jointly implemented. Farmers are an integral part of the design and implementation of the experiments, researchers learned from farmers what are the important variables to investigate and farmers learn from researchers how to set up an experiment. The costs of such experiments are low and farmers can implement them easily. The analyses might require input from experts or technicians. The samples are assessed by importers and represent the market preferences; this is novel in comparison to the quality information of volume, coffee which is not assessed in the same depth. The importers' appraisal of the coffees provides feedback to the farmers and permits a real world cost-benefit analyses.

7. 3.3 Can site specific farm management be applied generally?

For the proposed concepts to be applicable elsewhere, it is assumed that there is heterogeneity of growing conditions and a varied response to uniform management and technologies. Under these conditions, blanket recommendations for regions or zones does not optimize management for specific crops directed to particular markets. Although initial improvements can be obtained by using widely adapted technology, later improvements can come only from more site-specific technology (Cassman, 1999; Cock and Luna, 1996; Cook et al., 2000; Evenson, 1981). Farmers have long been aware of the differences among sites and constantly try out new options and adopt practices suited to their conditions. Due to the limited number of treatments that any one farmer can try and to the effects of variations in climate and other management practices, it may be difficult for a farmer to filter out the best options.

Supply chain management (SCM) for differentiated, higher-value crops emphasizes the overall and long-term benefit of cooperation and information sharing by all chain members. Relevant information for better decisions can then be provided to growers. Chain integration has been shown to improve the information flow concerning customer preferences (Trienekens et al., 2003). The literature review examined the widespread applicability of such chain integration.

In the Piendamo estate, early harvest significantly improved beverage quality. In Costa Rica, coffee quality from early and peak harvest was significantly higher than for late harvest (Vaast and Bertrand, 2005). In the Concordia estate, the lower and medium canopy level scored better than the upper canopy regions. A study in Costa Rica demonstrated that there was a significant difference between upper canopy region and middle and lower canopy regions (Bertrand et al., 2004). Also other variable management practices that have not been considered here would benefit from the outlined concepts: for example harvesting beans with different maturity grades has been shown to impact coffee beverage quality (Barel and Jacquet, 1994). Furthermore, for wine it has been demonstrated that selective harvesting provides for substantial benefits from systematic management of variation (Bramley et al., 2003).

The immediate processing of the harvested berries is more crucial in El Tambo-Timbio than in Inzá. The reason for this regional differences might lie in the lower average elevation of the El Tambo-Timbio farms (115 m lower), which gives higher annual average temperatures (0.9 °C higher) and accelerates microbiological processes in the mucilage. In addition the average annual precipitation (680 mm/year) and the annual average radiation are also higher in El Tambo-Timbio (24.9 Mj/m2day) than in Inzá (24 Mj/m2day). All these factors promote faster uncontrolled biochemical processes of the berries before they reach the processing plant.

Farmers adjust fermentation times according to their farm location. The reason is the decreased microbiological activity during the fermentation in farms of higher altitude or lower average temperatures. The location of the farm is in this case mainly characterized by air and water temperature factors that influence fermentation time. The results show that fermentation time in El Tambo-Timbio ($r = 0.10$) and Inzá ($r = -0.06$) are not factors that limit quality; that is to say that farmers apply the appropriate fermentation according to their location. Fermentation processes can be monitored easily as has been shown in on-farm trials in Nicaragua (Jackels and Jackels, 2005).

The results show that sun drying is better than silo drying. This fact might be due to the “unnaturally” fast drying of the beans in a silo in contrast to the slow sun drying. The slower process probably causes less loss of aromatic and enzymatic substances important to the coffee aroma and flavor. The disadvantage of silo drying has been reported in a study conducted in Java (Wahyudi and Ismayadi, 1995) and for mild Colombian coffees (Puerta Q., 1996).

7.3.4 Can the information be delivered?

One of the key problems in precision agriculture is not information acquisition but its interpretation and the feed-back mechanisms that deliver the information in a usable form to growers (Cook and Bramley, 1998). The dynamics and complexity of food systems and their supply chains require the use of new technologies to realize the opportunity to differentiate products based on their quality. This means that along the supply chain information must be shared vertically in both directions.

Several recent developments in low-cost radio frequency identification (RFID) technology systems make it possible to track and trace agricultural products (grain, fruit and meat) from farm to fork (Hornbacker, 2005; Pena, 2004.). GeoTraceAgri is a user-friendly system that allows interested people to track the origin of products on the Internet. GeoTraceAgri, tracks and traces European agricultural products at all stages of production, processing, storage, and distribution. They use a variety of different platforms, languages, databases, mapping engines and spatial processing libraries. The data can be geo-referenced and visualized on the Internet using geo-portals such as Google Earth (Hornbacker, 2005).

Until recently, small- and medium-sized companies and producers in rural areas have remained outside the advanced, integrated supply networks because the information technology solutions enabling this transparency in supply chains was expensive and unaffordable for them. With the Internet as a medium to deliver real-time information to consumers on the quality status of products, the methodology now appears feasible for them and to be worthy of investigation. A different research branch of the present project has recently presented the concepts that govern the provision of innovative information within agriculture supply chains with small holder producers (Oberthür et al., 2006).

7.4 Conclusions

1. Biophysical and management factors have a variable impact on coffee beverage quality. There were statistically significant differences between slope aspect in Piendamo, varieties in Mexico, times of harvest in Piendamo, shade in Inzá and slope position in both Concordia and Piendamo.

2. The impacts of these factors were not consistence across all sites and they were not always statistically significant.

3. On-farm experimentation with biophysical variables and agronomic management practices have to be evaluated as to whether they generate commercial benefits.

4. According to the cost-benefit appraisal, is the value added by biophysical and agronomic management factors as follows: aspect and harvest per canopy highly, shade management medium, variety and fruit thinning medium to low, and slope position and harvest per canopy low.

5. Post-harvest processes have to be targeted to the farm location and have to be controlled and managed site specifically as do the biophysical and agronomic management practices.

6. Site-specific management, innovative experimental design combined with a participatory approach and real world quality data are essential to turn the comparative advantage of a high quality environmental niche into a competitive advantage, that is a niche where high-quality coffee is produced.

7. Farmers will be able to target their product to the dynamic requirements of a dynamic market by cycles of implementation, observation, interpretation and evaluation.

8. To make this happen, it is necessary to interlink the actors in the supply chain more closely, to facilitate data analyses and interpretation for farmers, and to develop appropriate feed-back mechanisms.

9. Systematic site-specific farm management is a promising opportunity for farmers to improve their livelihoods by producing coffees with added value.

8 QUALITATIVE QUALITY CONTROL METHODS

Specific objective 5: To determine the utility of qualitative quality control methods.

This chapter firstly discusses the constraints of sensorial analyses followed by the descriptive statistics of the data sets. It then compares cupper variability versus variability of environmental factors in a case study and finally draws some conclusions.

8.1 Background

8.1.1 Production versus evaluation variability

Quality management of specialty coffee requires by definition assessment of sensorial quality. Only through cupping can intrinsic quality be characterized, profiles established and specialty coffees differentiated from volume coffees. The central question is, are cuppers consistent enough to detect differences between qualities that are caused by the variable production environment (production environment = natural environment + farm management) or is the variability in the production environment too small for the cupper to distinguish it?

If cuppers can detect differences, there still remains the variability between cuppers. Throughout this thesis it had been shown that in many instances cuppers are indeed able to detect differences in the production environment. The question remains, however, if cuppers do not detect differences, does this mean that there are no differences or that they simply not detect them? In the studies presented here, in many cases it might be that interactions could not be satisfactorily identified due to the nature of the commercial samples that is the samples contain a certain level of variability or “noise”.

8.1.2 Subjectivity of sensorial quality analyses

The sensorial assessments of coffee are performed by experts, who in the specialty coffee sector are usually both cuppers and importers. Sensory experts are persons “with considerable experience and proven ability in sensory assessment of a given product under specific conditions” (Land and Shepherd, 1984). They are widely used in the coffee, tea, tobacco and wine industries (Gatchalian, 1981) where their judgment impacts on management decisions for purchasing, processing and marketing. Land and Sheperd (1984) classify people performing sensory assessments as follows (Land and Shepherd, 1984):

(a) Unqualified assessors are any people (,other than those in the following categories,) taking part in sensory tests;
(b) Selected assessors are those tested and chosen for their proven ability to carry out a particular test;
(c) An expert is a person with considerable experience and proven ability in sensory assessment of a given product under specified conditions; and
(d) A panel is a group of selected assessors chosen to participate in a sensory test

Hall (1958) points out the following disadvantages of only relying on experts as opposed to selected assessors (Hall, 1958), “The expert’s perception varies from day to day, the judgment may vary under the influence of external factors and may not be free from bias, the expert may not have the same perceptions as a trained sensory panelist, and it takes much time to train experts and is therefore very costly.”

Attempts to determine sensory characteristics by objective indicators have been made for fruits by assessing quality variables in gas or liquid stage with a so-called “electronic nose” or “electronic tongue”. Characterization of defects in apples (Di Natale et al., 2001), ripening stages in mandarins (Hernández Gómez et al., 2005), pears (Brezmes et al., 2000), shelf live of apples (Brezmes et al., 2001) and coffee aroma (Dirinck et al., 2002) were conducted successfully. The methods include mass spectrometer, voltametric techniques and electrochemical measurements. In contrast, cupping of coffee consists of olfaction, gustation, and mouthful assessments corresponding to the sensory evaluation of the volatile matter, the water soluble matter, and the tactile sensations on the palate. These are experienced separately by the palate’s sensors, which are subsequently processed in the brain and joined to an overall sensation called the cup profile. Despite the advances in scientific knowledge on coffee in the last 40 years, the origin of coffee flavor remains unclear and is not detectable by artificial intelligence. Approximately one thousand chemical compounds have already been found in roasted coffee (Clarke and Vitzthum, 2001), it is their presence; absence and combination make up the cup profile. For the sensorial analysis of coffee quality, cupping panels are indispensable.

8.2 Descriptive statistics

8.2.1 Sensorial evaluation

The descriptive statistics of the five cuppers that evaluated the samples in this chapter are shown in Table 43. Cupper three and four score lower than the remaining cuppers and cupper four lower than the others and has therefore higher variability in the scores indicated by the wider range and larger standard deviation. Highest scores are reached for clean flavor, cup, uniformity and acidity.

Table 43: Descriptive statistic of cuppers' sensorial evaluation

		Frag. aroma	Flavor	After-taste	Acidity	Body	Uniform-mity	Clean-cup	Sweet -ness	Over-all	Bitter-ness
ALL	MIN	4.00	4.00	3.00	3.50	3.00	2.00	2.00	3.00	2.00	2.00
	MEAN	6.24	6.20	6.10	6.37	6.29	7.25	6.69	6.12	6.15	5.95
	MAX	8.25	9.50	8.50	8.75	8.50	9.00	9.00	8.75	8.50	8.50
	STDEV	1.09	1.02	1.11	1.21	1.03	1.35	1.72	1.15	1.10	1.04
Cupper 1	MIN	4.50	4.00	4.00	4.00	4.00	5.00	2.00	4.00	4.00	3.00
	MEAN	6.92	6.54	6.29	6.30	6.03	6.70	6.14	6.59	6.27	5.96
	MAX	8.25	9.50	8.50	8.75	7.75	9.00	9.00	8.75	8.50	7.00
	STDEV	0.84	1.28	1.28	1.48	1.19	1.10	1.94	1.32	1.30	0.66
Cupper 2	MIN	6.00	5.00	5.00	3.50	6.00	5.50	2.00	4.00	5.00	5.00
	MEAN	6.91	6.48	6.38	6.62	7.29	8.01	6.53	6.69	6.38	6.86
	MAX	8.00	7.50	7.50	8.25	8.50	9.00	8.75	8.50	7.75	8.50
	STDEV	0.56	0.63	0.71	1.24	0.55	0.79	1.82	1.16	0.82	1.26
Cupper 3	MIN	5.00	5.00	5.00	4.50	5.00	5.00	4.50	5.00	4.75	4.75
	MEAN	6.13	6.04	6.22	5.94	6.20	6.73	6.37	6.19	6.13	5.51
	MAX	7.00	7.00	6.75	7.00	7.00	8.00	7.00	7.75	7.00	6.75
	STDEV	0.59	0.39	0.43	0.89	0.55	0.55	0.92	0.68	0.66	0.57
Cupper 4	MIN	4.00	4.00	3.00	4.00	3.00	2.00	2.00	3.00	2.00	2.00
	MEAN	4.78	5.09	4.66	5.89	5.17	6.06	5.86	4.78	5.00	5.08
	MAX	6.00	7.00	6.00	8.00	6.00	7.00	8.00	7.00	7.00	7.00
	STDEV	1.19	0.94	1.06	0.95	0.85	0.75	1.04	1.05	1.15	1.08
Cupper 5	MIN	5.00	6.00	6.00	6.00	6.00	7.00	6.00	6.00	6.00	6.00
	MEAN	6.50	6.86	6.92	7.11	6.75	8.75	8.47	6.36	6.86	6.31
	MAX	8.00	8.00	8.00	8.00	8.00	9.00	9.00	7.00	8.00	8.00
	STDEV	1.06	0.77	0.77	0.82	0.65	0.55	0.77	0.49	0.77	0.52

8.2.2 Sites and production environment

The three cupping samples each have different origins; two are from the municipalities of El-Tambo-Timbio and Inzá in the department of Cauca in and one from the municipality of Timana in the department of Huila. Inzá and Timana are located between the central and eastern cordilleras and El-Tambo-Timbio between the western and central cordilleras of the Andes. The average annual precipitation is similar in Inzá and Timana and both have one dry month a year. El Tambo-Timbio and Inzá have similar temperatures (average annual temperature, average annual dew point, and average annual diurnal temperature range). Elevation of the sites differ, Timana has the lowest altitude, El Tambo-Timbio is mid altitude and Inzá the highest. Slope is the same in Inzá and Timana (Table 44).

Table 44: Descriptive statistics of environmental factors

	°P	T	DP	DTR	DM	SR	S	EL
El Tambo-Timbio	2311	18.4	12.5	11.0	2	25	8	1720
Inzá	1668	17.8	12.0	10.6	1	24	17	1852
Timana	1625	19.2	14.2	9.9	1	24	17	1517

P = average annual precipitation (mm), T = average annual temperature (°C), DP = average annual dew point (°C), DTR = average annual diurnal temperature range (°C), DM = average annual number of dry months, SR = solar radiation ($MJm^{-2}d^{-1}$), S = slope (°) and EL = elevation (masl).

The production system of El Tambo-Timbio is organic whereas both Inzá and Timana are traditional low input systems. The coffees are all Caturra variety with some shade cover. The post-harvest processes were the same traditional method for all the three samples with de-pulping and mucilage removal by fermentation. The coffees in Inzá and Timana were dried in the sun with a protective cover; the coffee in El Tambo-Timbio was dried in the sum on the floor without a protective cover (Table 45).

Table 45: Description of agronomic management and post-harvest processes

	Production system	Variety	Shade	Post-harvest Process	Drying
El Tambo-Timbio	Organic	Caturra	Some	Traditional	Sun on the floor
Inzá	Traditional	Caturra	Some	Traditional	Sun under protection
Timana	Traditional	Caturra	Some	Traditional	Sun under protection

8.3 Cupper consistency and sensitivity

8.3.1 Error matrix

The assessment of the environmental versus the cupper variability can be summarized in an error matrix (Table 46). Either there is variability in the environment expressed in the samples or there is not. If there is variability and the cupper does identify it, the results will be correct; if he does not recognize it then the result will be false. If there is no variability in the environment and the cupper does not differentiate the samples the result will be correct, if there is no variability and the cupper does detect variability the results will be false.

The error of differentiating the samples when there is no variability can be avoided by comparing the results of several cuppers, since it is very unlikely that a number of cuppers will discriminate samples if they are not different. The comparison of cuppers also helps to avoid the error of not distinguishing between the samples when there is variability. The case may be that there is variability between the samples but none of the cuppers is able to detect it, but the magnitude of this variability is not important in the assessment because if several experts canot distinguish the differences nor will the consumers be able to do so.

Table 46: Error matrix

		Environment	
		Variable	**Not variable**
Cupper	Defines variability	Correct	False
	Does not define variability	False	Correct

8.3.1 Cupper comparison

The ten sensorial attributes of each of the three samples with its replications were compared for each of five cuppers. The test of significance for cuppers one and two show that nine of the comparisons of El Tambo-Timbio with Inzá and Timana were assessed as statistically significantly different, for cupper three there were six attributes distinguishing the samples. For cupper four only one attribute distinguished El Tambo-Timbio from Timana, while cupper five did not distinguish between any of the samples (Table 47). According to the error matrix, the El Tambo-Timbio sample was different to the Inzá and the Timana samples, which were similar.

Table 47: Test of significance for sensorial attributes of samples
The roman numbers indicate the number of attributes out of a total of ten that were statistically different for the respective sample pairs.

	Sanple	n	El Tambo-Timbio	Inzá	Timana
Cupper 1	El Tambo-Timbio	11	--	IX	IX
	Inzá	10	IX	--	0
	Timana	12	IX	0	--
Cupper 2	El Tambo-Timbio	6	--	IX	IX
	Inzá	12	IX	--	0
	Timana	12	IX	0	--
Cupper 3	El Tambo-Timbio	12	--	VI	VI
	Inzá	12	VI	--	0
	Timana	12	VI	0	--
Cupper 4	El Tambo-Timbio	12	--	0	I
	Inzá	8	0	--	II
	Timana	12	I	II	--
Cupper 5	El Tambo-Timbio	11	--	0	0
	Inzá	12	0	--	0
	Timana	11	0	0	--

The principal component analyses (PCA) for cuppers one and two confirms these findings (Figure 36 and 37). El Tambo-Timbio replicate samples cluster mainly in the upper left quadrant while Timana and Inzá are crowded together and are distributed over mainly the upper and lower left quadrant. Visually it is apparent that El Tambo-Timbio is easily distinguishable from Inzá and Timana but Inzá and Timana are not so easily distinguishable.

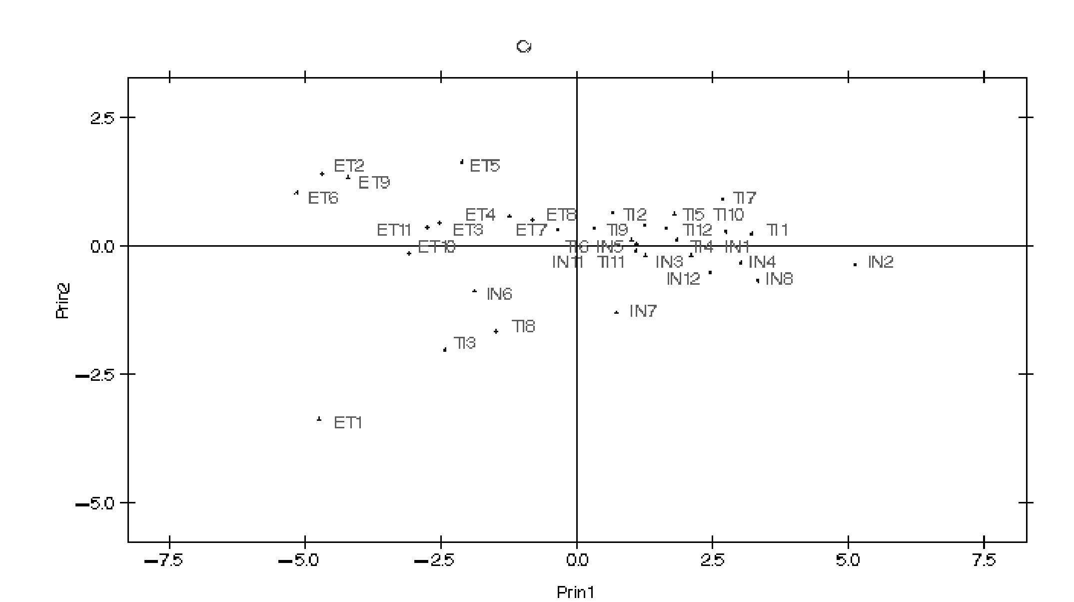


Figure 36: PCA analyses for cupper 1.

The analyses show the clustering of the replicate samples cupped by cupper 1. ET = El Tambo-Timbio, IN = Inzá, TI = Timana. Numbers 1-12 refer to the replicates of the samples.

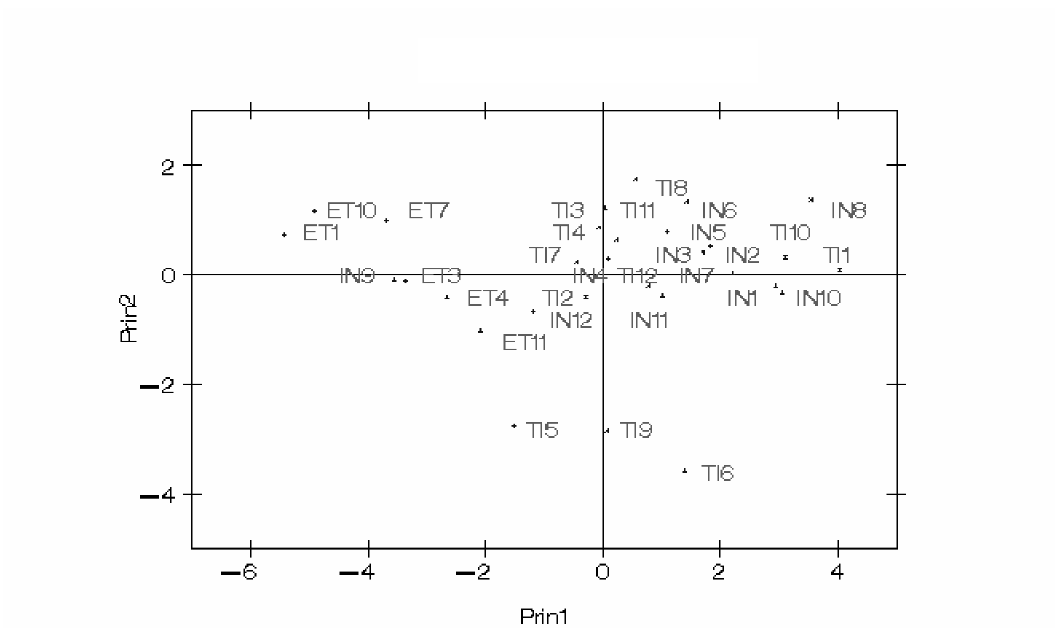


Figure 37: PCA analyses for cupper 2.

The analyses show the clustering of the replicate samples cupped by cupper 2. ET = El Tambo-Timbio, IN = Inzá, TI = Timana. Numbers 1-12 refer to the replicates of the samples.

The discriminate analyses shows that cupper one assigned only one replicate wrong for each sample, Inzá and Timana were classified wrong twice, El Tambo-Timbio and Timana only once, while Inzá and El Tambo-Timbio were always correct classified (Table 48).

Table 48: Discriminate analyses for cuppers 1 and 2

Number indicates samples correctly assigned by the cupper, e.g. cupper one identified ten of eleven El Tambo-Timbio replicate samples as El Tambo-Timbio and only one as Timana.

	Sample	El Tambo-Timbio	Inzá	Timana
Cupper 1	El Tambo-Timbio (n=11)	10	0	1
	Inzá (n=10)	0	9	1
	Timana (n=12)	0	1	11
		El Tambo-Timbio	**Inzá**	**Timana**
Cupper 2	El Tambo-Timbio (n=6)	6	0	0
	Inzá (n=12)	0	9	3
	Timana (n=12)	0	3	9

Cupper two distinguished bewteen Inzá and El Tambo-Timbio and between Timana and El Tambo-Timbio, but failed six times to distinguish between Inzá and Timana. These examples illustrate that the El Tambo-Timbio sample was different from the Inzá and Timana samples, which were similar and that the cuppers were able to distinguish the differences. In this case the variability of the environment is greater than the sensory variability of the cuppers who were able to detect the differences.

In summary:

Variability of cuppers < Variability in environment

Cupper three was similar to cuppers one and two, but was less sensitive. The discriminate analyses (Table 49) show that he was able to distinguish between the samples satisfactorily and the PCA (Figure 38) shows a nice clustering of the EL Tambo-Timbio samples and the crowded pattern of the Timana and Inzá samples. The differentiation is not as good as the one of cupper one and two, however, but cupper three was able to distinguish samples from El Tambo-Timbio from those from Inzá and Timana.

Again, in summary:

Variability of cuppers < Variability in environment

Table 49: Discriminate analyses for cupper 3

Cupper 3	El Tambo-Timbio	Inzá	Timana
El Tambo-Timbio (n=12)	10	1	1
Inzá (n=12)	0	10	2
Timana (n=12)	0	0	12

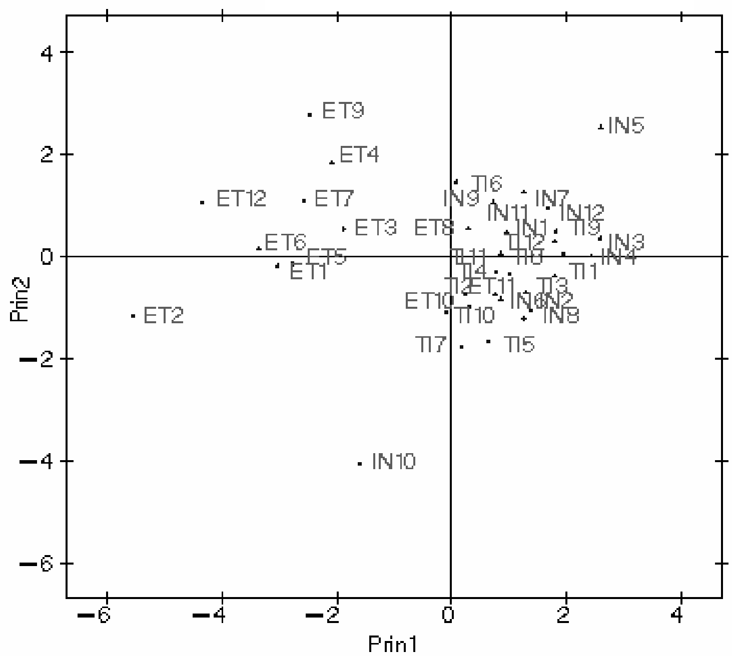


Figure 38: PCA analyses for cupper 3.

The analyses show the clustering of the replicate samples cupped by cupper 3. ET = El Tambo-Timbio, IN = Inzá, TI = Timana. Numbers 1-12 refer to the replicates of the samples.

According to the discriminate analyses cuppers four and five did not distinguish any sample without errors apart from cupper four distinguished Timana without error (Table 50).

Table 50: Discriminate analyses for cuppers 4 and 5

	Samples	El Tambo-Timbio	Inzá	Timana
Cupper 4	El Tambo-Timbio (n=12)	9	2	1
	Inzá (n=8)	1	7	0
	Timana (n=12)	0	0	12
Cupper 5	El Tambo-Timbio (n=11)	8	1	2
	Inzá (n=12)	2	9	1
	Timana (n=11)	1	0	10

The PCA results show the same pattern, the replicates of the three samples are crowded together with no discernable (Figure 39 and 40) distinguishable.

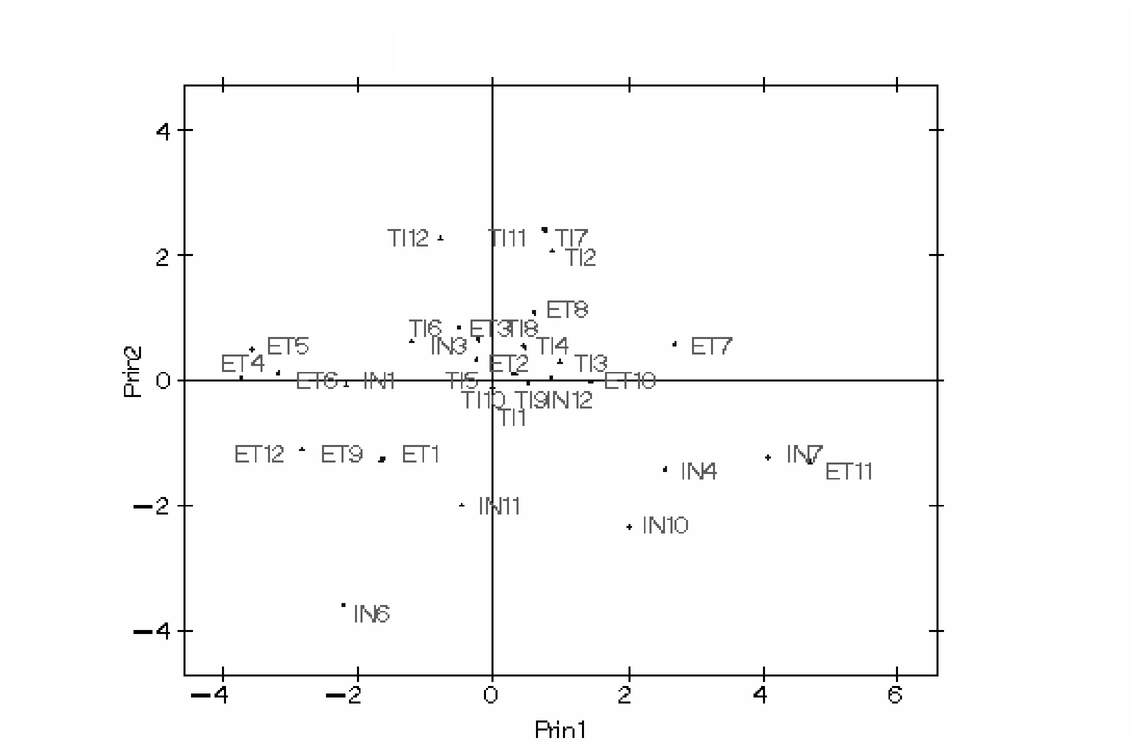


Figure 39: PCA analyses for cupper 4.

The analyses show the clustering of the repetition samples cupped by cupper 4. ET = El Tambo-Timbio, IN = Inzá, TI = Timana. Numbers 1-12 refer to the repetitions of the samples.

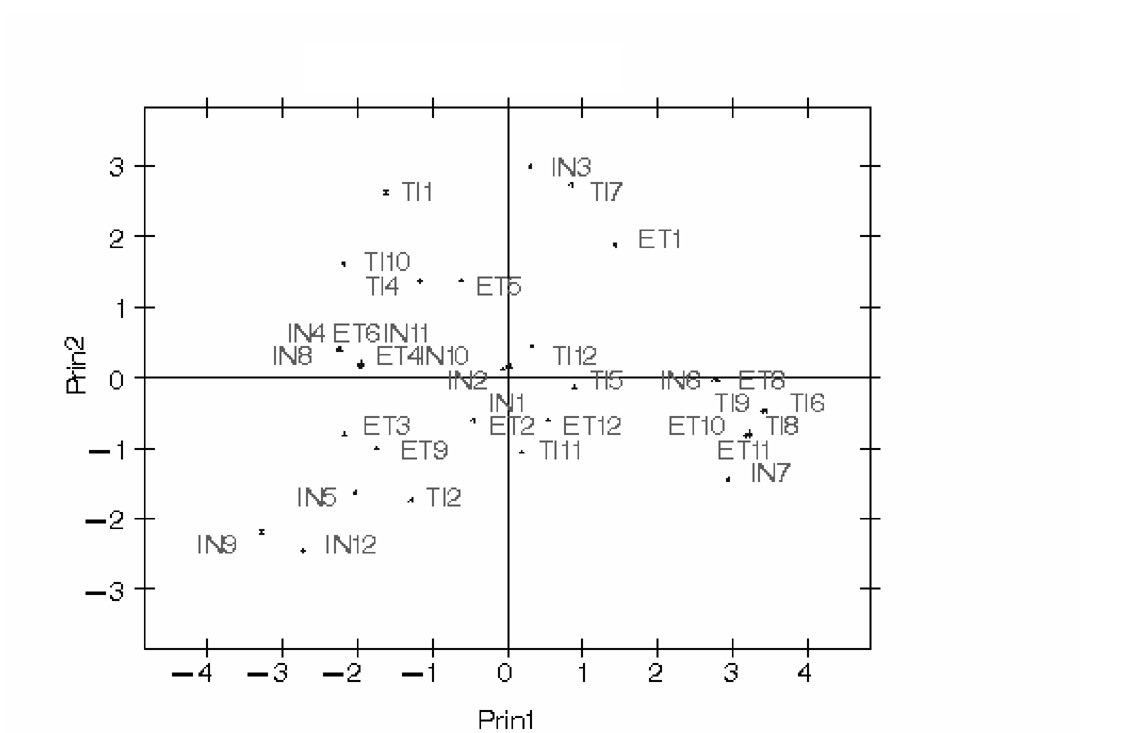


Figure 40: PCA analyses for cupper 5.

The analyses show the clustering of the repetition samples cupped by cupper 5. ET = El Tambo-Timbio, IN = Inzá, TI = Timana. Numbers 1-12 refer to the repetitions of the samples.

Cuppers four and five represent the case where the variability of the assessors is higher than the variability between the samples. The cuppers were not consistent in their judgment and did therefore not distinguish the samples.

In summary:

Variability of cuppers > Variability in environment

It is interesting to note that the consistent cuppers are representatives of a coffee exporting company. They know Colombian coffees very well and can distinguish accurately between the coffees grown between the western and central cordilleras (El Tambo-Timbio) and the coffees grown between the central and eastern cordilleras (Inzá and Timana). The two groups of samples are mainly characterized by their humidity regime, which is drier in the eastern (Magdalena) valley than in the western (Cauca) valley, together with the organic production in the western valley versus the traditional system in the eastern valley and the sun drying on the floor in the western valley versus the sun drying under protection in the eastern valley. Cuppers four and five on the other hand are international cuppers and undoubtedly know many coffees around the world but clearly were not able to distinguish local differences.

The findings demonstrate the importance of validation of the cupping data before conducting any further analyses. It is necessary to cup samples in a panel in order to use the data set of the most consistent cuppers for the analyses.

8.4 Conclusions

1. By definition, management of the quality of specialty coffees requires an assessment of sensorial quality. Only through cupping can intrinsic quality be characterized, profiles established and specialty coffees be differentiated from volume coffees.

2. Analyses of sensorial quality are very subjective and vary from one cupper to another.

3. Attempts to determine sensory characteristics using objective indicators have been reported. However, the cupping process involves variable sensations of the palate, which are experienced separately and are processed subsequently in the brain and joined together to an overall sensation called the cup profile.

4. It is crucial to know if the cupper variability (inconsistency of the cupping) is bigger or smaller than the variability required to be detected between the samples.

5. Analytical means of assessing the consistency of cuppers are essential. Discriminate analyses and PCA can help to chose consistent cuppers who have a sensible perception for quality differences.

9 FINAL EVALUATION

9.1 Evaluation of the conceptual frame work

The conceptual framework presented is highly viable for the management of intrinsic coffee quality (Table 51). High-quality niches exist that represent a comparative advantage for farmers. There are only a limited number of factors that determine the majority of variability in beverage quality of coffee as has been observed according to the Pareto Principle of quality control in manufacturing and industry. Limiting factors can be identified by analytical techniques and appropriate experimental design.

The information generated within the conceptual frame work is highly novel (Table 51). The consumer's perception is represented by the use of commercial data and product specifications, which are derived from the data according to the house of quality. The commercial data makes the analyses relevant to the participants of the supply chain. Prediction data is site-specific and readily available for any location.

Table 51: Validation of the conceptual frame work

4 stage approach to variability	Environment quality	Management quality
I: Is the conceptual frame work viable?		
-> Concept of comparative and competitive advantage	High	High
-> Pareto Principle		
-> Identification of limiting factors		
II: Is the information novel?		
-> House of quality	High	High
-> New product data		
-> New environmental data		
III: Is the information actionable?		
-> Taguchi concept	High – (medium)	High – (medium)
-> Realize the competitive advantage		
-> New techniques for data analyses		
IV: Can the information be delivered to the stakeholder?		
-> New feedback mechanisms	Medium	Medium
-> New information management systems		

The information generated within the conceptual framework is highly actionable for members of the supply chain but requires some input from experts with analytical and interpretative skills (Table 51). Reducing the variation around the quality target can be achieved by a cyclic learning process of information acquisition, interpretation, evaluation and control according to the Taguchi concept. The only systematic way to turn a comparative advantage into a competitive advantage is to shift from product control to process control by implementing a process control system. The evolution in computer hardware and software and new data mining and analyses technique support the system.

The information generated within the conceptual framework is deliverable given certain organizational structure and technical prerequisites (Table 51). Systematic data gathering and feedback systems have been successfully developed and tested. The data can be generated, and analyzed and interpreted. However, the data have to be compiled and fed into the system and the information returned to the participants. Technically this is no longer a problem but to get people to compile data and act upon the recommendations coming out of the feedback is still a challenge. The information has to reach growers and has to be in a form usable by them.

9.2 Test of the analytical framework

The equation of the analytical framework to be tested is: Livelihoods at site *i* are a function of income generated from quality *q*. Quality *q* at site *i* is a function of the farm management at site *i*.

$$LIV_i = f(INC_q) = f(QUA_i) = f(MGT_i) \quad (15)$$

Farm management at site *i* determines the product quality. The farm management has to be site specific to site *i*. Superior sensorial quality is rewarded by the market, increases income of growers and improves their livelihoods. The equation established is correct and explains the relation between growers' livelihoods, their income, their location and their production.

9.3 Overall Conclusions

1. The production environment for coffee (natural environment, agronomic management and post-harvest processes) is variable over space.

2. Beverage quality of coffee is dependent on the production environment. The combination of decisive quality factors varies from location to location, and so does the contribution each factor makes.

3. Production factors can be identified and their impact quantified. Subsequently, the factors can be systematically controlled and managed to improve product quality.

4. Site specific systematic and cyclic quality control processes are required to decrease produce variability and deliver the high-quality products sought of by the market.

5. The approach is twofold; firstly the identifaction of suitable environmental niches followed by the definition of site-specific management.

6. Farm management interventions are not always statistically significant but are often relevant for farmers.

7. Methods of qualitative quality control using commercial data are viable tools to measure product quality so long as consistent, skilled evaluators (cuppers) are selected in preliminary testing.

9.4 Recommendations

1. The developed framework should be implemented in a purely commercial setting with a large number of growers to refine the analyses, processes and experimental design further.

2. During the research reported here, some consultancies were undertaken to apply the framework. However the breakthrough that industry partners fully implement the ideas described here has not yet happened. It might be useful to investigate the reasons for the slow adoption of the concepts and framework.

3. The last mile in the supply chain is the most important and challenging researchable issue. How can growers be linked into the system and how can systematic process control be assured.

4. Using commercial data for research is logistically and analytically highly complex, but should more often be adopted in order to provide grower with results that are relevant to their situations and not merely statistically significant.

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11 ANNEX

10.1 Producer and standardized sample (CIAT) identification

PRODUCTOR

CIAT — Centro Internacional de Agricultura Tropical / International Center for Tropical Agriculture

Identificacion de muestras

Form 00a - Muestras Productores Impreso: 4/24/2006

Fecha de hoy: ____

Entregado a: ____

Peso Muestra: [kg] ____

Peso Lote Total: [kg] ____

Codigo Finca: F ____ **Codigo U. de Manejo: M-** ____

Nombre productor: ____

Nombre finca: ____

Cedula: ____

No. Tel (Celular o fijo) ____

Observaciones / Comentarios:

Fecha de cosecha: [aaaa-mm-dd] ____

Horas despues de la cosecha: [h] ____

Proc. Postcosecha: (eliga con x)

- ☐ Humedo
- ☐ Seco
- ☐ Mixto

Tiempo fermentacion: [h] ____

Secamiento: (eliga con x)

- ☐ Patio (Solar - patio)
- ☐ Parabolico (Solar - parabolico)
- ☐ Silo (Mecanico - silo)
- ☐ Guardiola (Mecanico - guardiola)

Tiempo: [h] ____

LoteId: (para llenar por CIAT)

**** CIAT ****

CIAT — Centro Internacional de Agricultura Tropical / International Center for Tropical Agriculture

Identificacion de muestras

Form 00b - Muestras CIAT Impreso: 4/24/2006

Fecha de hoy: ____

Observaciones / Comentarios:

LoteId:

Codigo Finca: F ____ **Codigo U. de Manejo: M-** ____

Nombre productor: ____

Nombre finca: ____

Cedula: ____

No. Tel (Celular o fijo ____

Beneficio: **Fecha y hora inicio beneficio** ____

1] Recolección / recibo de café

Peso muestra recolectada: ____ [kg]

2a] Despulpar / desmucilaginar

Horas despues cosecha: [h] ____

Hora al comenzar despulpar: [h] ____

Peso muestra desmucilaginada: ____ [kg]

2b] Fermentación:

Hora al comenzar fermentar: ____

Hora finalizar: ____

Peso muestra fermentada: ____ [kg]

3] Lavado

Cuantas veces lavado: ____

4] Secado

Nr caja secador: ____

☐ temperatura NO supera 45ºC

Hora entrada: ____ Hora salida: ____

Humedad final: ____ [%]

Peso muestra secada: ____ [kg]

Fecha y hora de cumplir post cosecha ____ Firma ____

10.2 General farm and post-harvest facility data capturing form

Datos FINCA - Proyecto DAPA - (c)2006 CIAT

printed: **ENCUESTA No. 1**

00] Codigo Finca: **F-**

Fecha manip: Id:

CIAT – Centro Internacional de Agricultura Tropical – International Center for Tropical Agriculture

01] Activo: ______ [s/n]

02] Fecha Visita: ______ [aaaa-mm-dd]

03] Encuestador: ______

04] Nombre Finca: ______

05] Nombre Productor: ______

06] Municipio: ______

07] Vereda: ______

08] Corregimiento: ______

09] Departamento: ______

09a] Pais: ______

10] No. Identificación: ______

11] Lugar de Expedición: ______

12] No Telefono Celular: ______

13] No Telefono Casa: ______

14] Correo Electronico: ______

15] Informacion geografica y meteorologica (marca con X):

- ☐ Plano de la Finca ☐ Mapeo GPS
- ☐ Fotos aereas ☐ Otro/Note: ______

20] Notas Finca:

Nota: Por favor dibujar un plan de la Finca con sus lotes y unidades de manejo en el dorso >>>>>>

16] Asociacion: Nombre: ______ Contacto: ______

16a] Asociacion 1: Nombre: ______ Contacto: ______

17] Area total de la finca: ______ [m2]

17a] Area total en café: ______ [m2]

18] Otras Fincas de su propriedad: ______

19] Fecha floración: ______ [mm-dd]

Datos PRACTICAS POST-COSECHA

F-Manip: Id:

21] Descripcion Proceso De Post-Cosecha:

- ☐ Recolectar ☐ Desmuciligar ☐ Lavar
- ☐ Despulpar ☐ Fermentar ☐ Secar
- ☐ Otros: ______

22] Tipo de Beneficio: ______

23] Marca: ______

24] Capacidad despulpadora: ______ [kg/h]

25] Tiempo de cosecha hasta beneficio: ______ [h]

26] Año de construción de la despulpadora: ______

27] Estado beneficio y ambiente de trabajo: ______

28] Selecciona grano: ______

29] Tiempo de fermentación: ______ [h]

30] No. lavadas despues de fermentar: ______

31] Tipo de secado: ______

32] Tiempo de secado : ______ [h or d]

33] Notas Practicas Post Cosecha:

10.3 Managemnt Unit (MU) data capturing form

Datos UNIDAD DE MANEJO - Proyecto DAPA - (c)2006 CIAT

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

printed: **ENCUESTA No. 2**

01] Codigo Finca: **F-** [Nombre Finca:]
[Nombre Productor:]

02] MU-Code: M-		
03] Nombre:		
04] Descripcion:		
05] Fecha creacion: [aaaa-mm-dd]		
06] Latitud Centro: [g. dec]		
07] Longitud Centro: [g. dec]		
08] Altura Centro: [m]		
09] Area total UM: [m2]		
10] Nota:		

02] MU-Code: M-		
03] Nombre:		
04] Descripcion:		
05] Fecha creacion: [aaaa-mm-dd]		
06] Latitud Centro: [g. dec]		
07] Longitud Centro: [g. dec]		
08] Altura Centro: [m]		
09] Area total UM: [m2]		
10] Nota:		

02] MU-Code: M-		
03] Nombre:		
04] Descripcion:		
05] Fecha creacion: [aaaa-mm-dd]		
06] Latitud Centro: [g. dec]		
07] Longitud Centro: [g. dec]		
08] Altura Centro: [m]		
09] Area total UM: [m2]		
10] Nota:		

10.4 Field data capturing form

Datos FIELDS - Proyecto DAPA - (c)2006 CIAT

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

printed: **ENCUESTA No. 3**

01] Codigo Finca: **F-** [Nombre Finca:]
[Nombre Productor:]

F.-Manip.:
Id:

02] Codigo unidad de manejo: **M-**		
02a] Nombre unidad de manejo:		
03] Nombre lote:		
04] Area / Tamaño Lote: [m2]		
05] Variedad: [L]		
06] Origen de chapola:		
07] Fecha siembra: [aaaa-mm-dd]		
08] Año de soqueo: [aaaa]		
09] Tipo de soqueo: [L]		
10] Numero soqueos: [No]		
11] Numero chupones: [No]		
12] Numero de matas (café) por lote: [No]		
13] Distancia de siembra: [matas x filas][m x m]		
13a] Siembra:		
14] Sistema de siembra: [L]		
15] Especies asociados / sombrio: [L]		
20] Sistema de producción [L]		
21] Arboles de sombrío por ha: [arboles / ha]		
22] Distancia de siembra de sombrío: [m]		
23] Tipo de control de arvense (malezas): [L]		
24] Cuantas veces fertilizan: [No]		
25] Tipo de control de enfermedades: [L]		
26] Nota:		

10.5 Illumination study data capturing form

Datos ENSAYO DE ILLUMINACION
Proyecto DAPA - (c)2005 CIAT

Fecha impreso: 9/29/2005 **ENCUESTA No. 5**

01] Codigo Finca:	**[F-]**	
02] Codigo UM:	**[M-]**	
03] Numero Ensayo:	**[IL-]**	
04] Area ensayo:	[m2]	
05] Orientación:	[gr]	
06] Pendiente:	[%]	
07] Vigor mata de café:		Altura: [cm] ______ Ancho: [cm] ______

	Punto Central (PC)	Punto 1 (P1)	Punto 2 (P2)	Punto 3 (P3)	Punto 4 (P4)
08] Fecha medición: 09] Hora medición:					
10] Codigo GPS: 11] Latitud: [g. dec] 12] Longitud: [g. dec] 13] Altura: [m]					
14] Ref. Medicion Iluminacion:					
15] Altura [cm]:					
16] Fotos Ensayo / Sitio:					
17] Descripcion:					
18] Nota:					

10.6 Fermentation study data capturing form

IDENTIFICACION DE MUESTRAS - Estudio De Fermentación

Printed: 9/29/2005

ENCUESTA No. 07

Codigo Finca: [F-XXX] F-________

Codigo Unidad de Manejo: [M-XX M-________

Nombre finca:________

Nombre productor ________

Nombre Lote: **EF-**________

Fecha de hoy: ________ [aaaa-mm-dd]

Observaciones / Comentarios:

Beneficio: **Fecha y hora inicio benefici** ________

1] Recolección / recibo de café

- ☐ solo maduro
- ☐ sacar verde
- ☐ sacar seco
- ☐ sacar ojas / piedra
- ☐ sacar brocado
- ☐ canasta limpia

Peso muestra recolectada: ________ [kg]

2a] Despulpar / desmucilaginar

- ☐ limpiar equipos
- ☐ ajustar equipos
- ☐ despulpar inmediatamente después de cosechar

Horas despues cosecha: [h] ________

Hora al comenzar despulpar: ________

Peso muestra desmucilaginada: ________ [kg]

operación correcta del equipo:

- ☐ separa y elimina pulpa
- ☐ mucílago esta retirado completamente del grano

2b] Fermentación:

Hora al comenzar fermentar: ________

Hora finalizar: ________

Hora de revolver:

01] ________	08] ________
02] ________	09] ________
03] ________	10] ________
04] ________	11] ________
05] ________	12] ________
06] ________	13] ________
07] ________	14] ________

Peso muestra fermentada: ________ [kg]

3] Lavado

- ☐ utilizar agua potable
- ☐ revisar calidad de café lavado

Cuantas veces lavado: ________

4] Secado

Nr caja secador: ________

- ☐ solo secar café bueno
- ☐ café NO lleva granos defectuosos
- ☐ café NO lleva granos con pulpa
- ☐ café NO lleva pasilla
- ☐ café NO lleva mucílago adherente
- ☐ temperatura NO supera 45ºC

	Entrada:	Salida:
Hora entrada piso 1 (arriba):		
Hora entrada piso 2:		
Hora entrada piso 3:		
Hora entrada piso 4 (abajo):		

Humedad final: ________ [%]

Peso muestra secada: ________ [kg]

Fecha y hora de cumplir post cosecha ________ Firma ________

10.7 Cupping form

Catación de Cafe

v1.2_2005-07-25_GoffWatts_TimCastle_FernandoGomez

Printed: 9/29/2005 **ENCUESTA No. 08**

CIAT — Centro Internacional de Agricultura Tropical / International Center for Tropical Agriculture

catador: ____________ lugar: CafiCauca

fecha de catación: 2005- ________ codigo catacion C- ________ mesa no.: ________

nivel de tostado ____ [0 - 6]

fragancia/aroma ____ [5.00 - 10.00]

intensidad aroma ____ [0 - 5]

eliga:
- Floral
- Frutal
- Herbal
- Anuesado
- Picante
- Caramelo
- Chocolate dulce
- Chocolate amargo
- Vanilla
- Citrico
- Neutral
- Resinoso
- Carbonoso

nota

sabor ____ [5.00 - 10.00]

eliga:
- Floral
- Frutal
- Herbal
- Anuesado
- Picante
- Caramelo
- Chocolate dulce
- Chocolate amargo
- Articulado
- Vanilla
- Citrico
- Melon
- Mora
- Vinoso
- Carbonoso
- Madera
- Resinoso
- Neutral

nota

sabor residual ____ [5.00 - 10.00]

eliga:
- Refrescante
- Limpio
- Dulce
- Picante
- Delicado
- Suave
- Duro
- Astringente
- Amargo
- Seco
- Agrio
- Vinoso
- Aspero
- Salado

nota

acidéz ____ [5.00 - 10.00]

intensidad acidéz ____ [0 - 5]

uniformidad ____ [0 - 5]

balance ____ [5.00 - 10.00]

cuerpo ____ [5.00 - 10.00]

nivel cuerpo ____ [0 - 5]

taza limpia ____ [0 - 5]

dulzor ____ [0 - 5]

puntaje catador ____ [5.00 - 10.00]

defectos

enteros:	**tazas**
Fermento	
Metálico	
Químico	
Vinagre	
Stinker	
Fenol	
Reposo	
Moho	
Terroso	
Extraño	
Sucio	
Astringente	

ligeros:	**tazas**
Cereal	
Fermento	
Reposo ligero	
Moho	
Astringencia	

notas catación