SYSTEMATIC AGRONOMIC FARM MANAGEMENT FOR IMPROVED COFFEE QUALITY

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ABSTRACT

There is growing interest of international markets in differentiated agricultural products from the tropics. Coffee is a tropical crop of relatively high quality, whose value is increasing as consumer demand in developed countries for speciality coffee. Smallholders in emerging markets can benefit by capitalizing on the natural resource variability in their production system and from the knowledge that they have about this variability. The objective of this paper is to illustrate the benefits of systematically targeting management practices by coffee growers to improve attributes of their product. Data from case studies in Colombia and Mexico show statistically significant differences in beverage quality of coffees grown under different production conditions such as slope aspect, varieties, times of harvest, and shade levels. Possible intervention options can be selected by growers in terms of their ease of implementation, the likely improvement of quality that they achieve and the resource intensiveness they require. The conclusion is that optimum management is site specific so that it is not possible to make any blanket recommendations. Using continuous management cycles of implementation, observation, interpretation and evaluation the site specificity provides growers an opportunity to improve management over time to produce a higher quality product.

Keywords: *Coffea arabica*, sensory quality, site-specific management

1. INTRODUCTION

As *per capita* income increases, diets tend to diversify, and the proportion of expenditures for higher-quality differentiated foodstuffs increases relative to staples (Coyle et al., 1998). Product differentiation occurs when consumers see a product as distinct from its competitors in terms of perceived or real differences (Dickson and Ginter, 1987). Differentiation of agricultural products can be intrinsic to the product, symbolic of reputation, and be based on producer-consumer relationships (Daviron and Ponte, 2005). Many attributes can determine product quality, which in itself has much to do with personal preferences. In developed countries there is an increasing demand for specialty coffee (Byers et al., 2008). The expression of intrinsic quality attributes of coffee results from interactions among environment, genetic make-up of the plant, and management practices.

Management practices include pre- and post-harvest processing and roasting. The impact of both environment and management on quality has been demonstrated in various studies (Avelino et al., 2005; Muschler, 2001). Methods were developed to determine the impact of specific environmental factors (Läderach et al., 2009), but there has been done little research to demonstrate that growers can use experimental approaches to benefit from the interactions between quality and management. We hypothesize that there is an opportunity for coffee growers in favorable growing environments to capitalize on the natural resource variability in their production systems. From the knowledge that they have about this variability they can identify and employ particular management practices that consistently produce the desired quality attributes, as it has been shown previously for wine (Salette et al., 1998) and coffee (Läderach et al., 2009)

The objective of this paper is to illustrate the process of systematic targeting of management practices by smallholder growers and their supply-chain partners using the case of specialty coffee. We first present the conceptual background, and then illustrate the process of targeting management practices with data from case studies representing diverse production scenarios in Colombia and Mexico. We used examples of diverse production systems to test if the concept holds across the systems.

2. CONCEPTUAL BACKGROUND

The notion of managing variation is intuitively appealing to growers who are experts in identifying local variability in their resource base (Oberthür et al., 2004). In explicitly recognizing spatial and temporal variation, the approach of precision agriculture differs from conventional reductionist agricultural research (Bramley, 2009). In many situations, the likely gains from explicit definition of spatial variation are sufficient to justify greater efforts to apply the principles of precision agriculture to the problems of agronomic management for product quality in developing countries (Cook et al., 2004).

Precision agriculture can be applied uniformly to an entire field to benefit from between field variability, or it can involve site-specific management within a field (Cassman, 1999). With annual crops grown in large fields in developed countries, precision agriculture has focused on within-field variation associated with variability in specific factors. In tropical agriculture in developing countries with perennial crops, however, fields, or management units within a field, are generally much smaller and are treated as homogenous in terms of crop response to management.

Moreover, producers lack techniques to associate within-field variation to variation in specific crop characteristics. The first step in precision agriculture in these circumstances should be precision management of fields, or management units, rather than of definition of in-field variation (Dobermann et al., 2004).

The approach we adopted to site-specific management of fields, or management units, is based on cycles of analysis and learning to find better ways of doing business (Cook and Bramley, 1998). With regard to coffee, the strategy is both to identify variation within the natural resource and its impacts on coffee quality, and also to superimpose variation in on-farm agronomic and processing practices and monitor their effects on product quality.

To resemble commercial farm operations as closely as possible, the sampling units we used on all farms were management units (MUs). MUs are land areas that can be independently managed by the grower during all production stages, including post-harvest processing of batches of coffee beans, as is implemented in wine using "terroir basic units (TBU)" (Morlat et al., 2006). The natural conditions of MUs are typically homogeneous in terms of, soil, topography, and weather. Depending on the technical infrastructure, an MU can be part of a field, a single individual field, a group of fields, or a complete small farm.

3. MATERIALS AND METHODS

3.1 Site selection and characterization

The study sites were on commercial farms with diverse production conditions. Specifically, the study examined two estate farms (> 25 ha) and 33 small farms (0.5–5.0 ha) in Colombia; and two farms of about 5 ha in Mexico (Figure 1). The estates in Colombia were located in the municipality of Concordia (6.03ºN, 75.89ºW, altitude 1870m in the department of Antioquia), and in the municipality of Piendamo (2.75ºN, 76.57ºW, altitude 1640 m in the department of Cauca). The 33 small farms were located in the municipality of Inza (2.47–2.53ºN, 75.99–76.02ºW, altitude 1630–1990m in the department of Cauca). The two Mexican farms were located in the state of Veracruz. One farm was in the community of El Encinal (19.21ºN, 96.82ºW, altitude 890m in the municipality of Totutla) and the other in the community of Auxcuapan (19.20ºN, 96.98ºW, altitude 1490m in the municipality of Tlaltetela). Commonly in Colombia the coffee producing areas range from 1500 to 2000 masl and in Veracruz from 500 to 1500 masl.

Figure 1 near here

The two estate farms in Colombia represented intensive, unshaded coffee-production systems. In the Concordia estate, the slope varies from 0 to 15° and the MUs have a wide range of topographical aspects. Annual precipitation is 2300 mm, mean annual temperature is 19.3°C and the soils are entisol-inceptisols. In the Piendamo estate the slopes range from 0 to 25°. Annual precipitation is 2200 mm, the annual mean temperature is 19.2°C and the soils are inceptisols. The small farms in Colombia varied widely in terms of shade levels, slopes, and aspect. Slopes ranged from 3 to 35° and averaged 20°. Annual precipitation ranges from 1580 to 1760 mm; and annual average temperature is about 18°C. The soils are principally entisols-inceptisols. The Mexican sites have flat topography. In El Encinal, annual precipitation is 1200 mm with a mean annual temperature of 21°C. Soils are inceptisols. Axocuapan has an annual precipitation of 1800 mm and an annual average temperature of 18°C. The soils are andisols. The climate data were extracted from the WorldClim database (Hijmans et al., 2005). WorldClim is an interpoloated climate surface based on data records from a variety of sources for the period 1950-2000. Its resolution is 30 arc seconds (often called 1-km spatial resolution).

3.2 Selection of biophysical variables and management practices

The different biophysical variables and management practices selected are shown in Table 1. The estate farms in Colombia provided the widest choice of management options. The growers identified five different management units in each estate that presented northern, western, southern and eastern aspect. In addition, one plateau MU was 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 slope positions. Within each MU an area of 30 x 30 m was selected for the study.

Table 1 near here

In each of the nine sites identified on the estate farms, different harvesting strategies were implemented after consultation with the growers. These included harvesting fruits separately from different 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 and fruits per node. The fruit thinning consisted in removing 50% of the fruits at each node nine weeks after the main flowering from 50 randomly selected trees in the selected plots. At this time the fruits had initiated the bean filling stage and had reached about 10% of their final size (Arcila-Pulgarín et al., 2002). We made two harvests in Piendamo, early

(12 May) and late (9 June) during the harvest peak from 50 randomly-selected trees. Apart from these treatments, the MUs were managed by the growers using their normal practices. Only ripe berries were harvested in all the experiments.

It was not possible to implement so many treatments on the small Colombian farms. Owners identified one MU in each of their farms in which we identified contrasting levels of shade density and selected uniform areas of 30 x 30m. Other agronomic management practices were very similar across all the small farms. In Mexico we determined, cultivar and shade levels for eight management units in El Encinal and four management units in Axocuapan. The cultivars sampled in El Encinal were Typica, Caturra Rojo, Caturra Amarillo, and Mundo Novo and in Axocuapan were Typica and Caturra Rojo. Other agronomic management followed local commercial standards and were similar across all MUs.

3.3 Harvest and processing

Twelve kg of ripe berries were harvested by hand during the peak of the 2006 harvest for each treatment using a standard 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. Berries were also 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 within the 30 m x 30 m area identified within the MU. Before processing, damaged, green, and infested 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 truck-mounted processing unit where the berries were de-pulped and the mucilage removed. The beans were subsequently fermented in 10-L buckets.

Samples of 1-1.5 kg were then dried using air heated to 45°C by a gas burner, adding the most recent samples in the top drawers of the drier and moving samples progressively down to the next lower level as new samples were added, emulating the process of industrial dryers. Samples were dried until the parchment beans reached a humidity of 10% to 12 %, which occurred in 14–16 hours. The samples were then placed in sealed plastic bags and stored at 18° C until the cupping process.

Samples from Mexico were harvested during the peak of the 2005/06 harvest. The samples 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 slightly different procedures used in Mexico and Colombia did not present a problem in the data analyses because we made no direct comparison of Mexican and Colombian samples. There is also no direct comparison of the results from the assessments of samples from the Colombian estates and small farms.

3.4 Physical assessment and beverage quality evaluation

The parchment beans were milled and the percentage and weight of bean and husks determined. Beans with primary and secondary defects were quantified, their weight and percentage recorded, and beans with defects removed by hand. The defect-free beans were sieved and the bean-size distribution determined using standard sieves from 0.55 cm to 0.71 cm. Only beans of sieve size 0.59 cm and higher were used for the analysis.

For each Colombian sample, 250 g of beans were roasted in a laboratory roaster (Probat BRZ-2) the day before the beverage assessment for about 11 minutes with an initial temperature of 200 °C to a common standard brown color. Color was controlled using Agtron /SCAA #85 light of the roast color classification system (Staub, 1995). Roasted beans were ground to intermediate particle size immediately before the beverage quality assessment using a precision grinder (Ditting/KFA 1403). Sensory assessment of beverage quality 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, flavour, 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, and especially weight. Flavor is the taste perception of the coffee beverage on the tongue. Sweetness is the detection of soluble sugars on the tongue tip. Preference represents the overall impression of the coffee by the cupper. 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 (Lingle, 2001).

The estate samples were cupped by Mr Geoff Watts, a cupper of high international reputation. The samples from the small farms were assessed by a national panel of several cuppers of which only the results of the most consistent cupper were included in the analyses. Cupper consistency was assessed using statistical discriminant function analyses (Hair, 1992). The national panel on average assigned lower values than the international cupper so that the results could not be analyzed jointly with the estate samples. The Mexico samples were assessed by a panel of seven cuppers in the cupping laboratory of Café-Veracruz, A.C. As suggested by the official Mexican norm only the attributes fragrance, aroma, aftertaste, acidity and body were assessed. Mexican cuppers used a scale that ranges from 0-15, 0-5 being low quality, 5-9 medium quality and >9 high quality.

3.5 Acquisition of environmental information

Geographic location of each MU was determined using a Trimble Pro-XR global positioning system (GPS) with Omni-STAR real-time correction. Aspect in degrees (°) was measured with a compass. To describe the shade density five hemispherical images were taken per sampling unit, one in the center and four on the diagonals at 2.2 m above ground 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 software to derive illumination parameters (Regentinstruments, 2005). First the pixels of the imagery were classified as canopy and sky, the output of which is a black and white image. The second step is the analyses of the canopy, which comprises canopy structure and radiation. The canopy structure variable derived for the present analyses was the gap fraction, the number of pixels classified as sky divided by total number of pixels. The shade percentage is the numerical complement (100% - gap fraction). WinSCANOPY was used to compute direct radiation above the canopy, which is based on latitude, longitude, and the defined growing season. 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 MJ m^{-2} d^{-1}. We assessed the impact of shade management on coffee-quality characteristics, by arbitrarily grouping the sites into high shade and low shade.

All field measurements, product quality assessment data and other information related to management practices were entered into CINFO (Niederhauser et al., 2008). CINFO is an interactive, online spatial data-management system for supply chains of higher-value agricultural products.

3.6 Statistical analyses

Data were exported from CINFO for statistical analyses in spreadsheet format and summary statistics were computed, the ANOVA analyses, and the Duncan tests were done using the S+ package (Insightful, 2001).

Information of sensorial beverage quality are on a quasi-interval scale (1 to 10 with increments of 0.5 giving 20 available points), which is analogous to a Likert scale. These data are usually analyzed using interval procedures in parametric statistical methods (Vaast et al., 2006; Decazy et al., 2003). In a review of the literature it has been concluded, "for many statistical tests, rather severe departures (from intervalness) do not seem to affect Type I and Type II errors dramatically"(Jaccard and Wan, 1996). They suggest, provided the scale has at least five, and preferably seven categories, the assumption of normal distribution can be assumed to be valid. In the estate farms in Colombia we made an analysis of variance considering the main effects (aspect, slope position, management), and the first-order interactions (aspect*slope, aspect*management and slope*management).

4. RESULTS

4.1 Summary for all sites

Table 2 summarizes the results of the coffee beverage sensory analyses.

Table 2 near here

The two Colombian estates have average values between seven and eight for the sensory characteristics, except for sweetness. Concordia tends to have higher values, which are also less variable as indicated by the smaller ranges and lower standard deviations, except for body and sweetness, which are less variable at Piendamo The Concordia average final score is more than 80 points, while the highest final scores for the both estates were more than 90 points. The Inza farms had relatively low values, between three and six, for the sensory characteristics, and the product quality of the 33 farms was highly variable. In contrast, the coffee quality within each of the two Mexican farms was very similar, although quality from the Axocuapan farm was slightly more variable (Table 2).

4.2 Biophysical variables

On the Concordia estate we did not detect any consistent effect of the slope or aspect on coffee quality. Best coffees came from the plateau site with a final score of 83.2. Berries harvested from south-facing slopes also scored well, with 82.9. The east-facing slopes were generally gave the lowest, but still acceptable scores of 80.7 (Table 3). The situation was different in the Piendamo estate where all aspects, except the south- and east-facing slopes, produced similar-quality coffees. The quality of coffee from the south-facing slope in this estate was generally poor (final score 71.0). Coffees from east-facing slopes scored best with a final score of 80.9. This represents an astounding difference of almost ten points between the best- and the worst-performing site on this estate.

Table 3 near here

Coffee quality was influenced by slope position with the higher-slope positions generally giving higher scores, although the differences were not statistically significant. The differences between best- and worst-performing coffees were again greater on the Piendamo estate than on the Concordia estate with three and less than one point in the final score, respectively. In Concordia only aroma/fragrance and preference appear to be better in coffee harvested in the lower slope positions. In Piendamo only body was perceived better when berries are harvested in lower positions on the slope. It is noteworthy that the ranges of aspect and slope values in the Piendamo estate were considerably greater than for the Concordia estate.

4.3 Variety choice

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. Typica and Yellow Caturra only achieved higher values for the body characteristic (Table 4). In Axocuapan, Typica performed best for fragrance/aroma and for body; and Red Caturra gave the highest values for acidity.

Table 4 near here

4.4 Shade management

At Inza, the mean shade level of the 17 sites in the low-shade class was 37% (range 26-49), while the 15 sites with denser shade averaged of 61 % (range 52-79, Table 5). The coffees from denser shade generally scored higher than coffees from lower levels of shade. The differences were consistent for all quality characteristics, except sweetness, although they were statistically significant only for body. The individual characteristics resulted in final scores of 53.2 for lower shade density and 56.3 for the higher shade class.

Table 5 near here

There were also consistent differences for shade in Mexico, where shade density was much higher, with the low shade group 68% coverage and the dense shade, 87%. In contrast to the Inza farms in Colombia, lower shade in Mexico gave better coffee than dense shade, although the differences were not statistically significant, except for body as at Inza.

4.5 Harvest management

Table 6 shows the effects of the different harvest management practices on the two Colombian estates.

Table 6 near here

Fruit thinning gave higher values for all quality characteristics in the Piendamo estate, except for flavor and aroma/fragrance. Final scores were 76.2 points for thinned coffee from compared to 74.6 points from trees with a full fruit load, although the differences were not significant. In the Concordia estate, the coffee from the no-thin treatment (84.3) scored better than the full-fruit-load treatment (81.1). The differences were significant for aftertaste and final score.

Early harvest generally gave better coffee than late harvest for all the coffee-quality characteristics apart from aroma/fragrance. Final scores for early- and late-harvested coffees were 77.8 points and 72.6 pints respectively.

Harvesting from different canopy levels in the Concordia estate also produced differences in beverage quality. Berries from the medium levels of the canopy had the highest final score for the beverage quality. However the differences were not consistent with different coffee-quality characteristics giving the highest scores for different canopy harvest levels. For example, aroma fragrance was significantly better in medium and high compared to low canopy levels; sweetness was significantly better in low and medium canopy levels and flavor significantly better in medium levels compared to high canopy levels.

6. DISCUSSION

Here we elaborate further on the most interesting findings from the field experiments (section 6.1). These findings are, however, site specific, so that it is difficult to generalize across locations. We therefore put particular emphases on providing further information about the process we used to implement the field research (6.2). It is the process of site-specific management that is transferable and thereby enables growers and their partners to identify what works best in their own production system. Finally, we provide some information as to whether the proposed management approach is financially viable (6.3).

6.1 Plant environment, and plant management interactions

Due to its elevation and climate, the Concordia estate is located in an optimum growing area compared with Piendamo, which is located on the border of the coffee-producing areas. Micro variations in climate are more important in marginal growing areas than in the main growing areas, therefore differences in slope are more pronounced in Piendamo, whose altitude is 230 m lower than Concordia. The south-facing slope receives more direct sunlight, which compromises coffee quality, while east-facing slopes, which are exposed to morning sunlight gives the highest quality (Avelino et al., 2005).

Light exposure of coffee berries affects their maturation (Barritt et al., 1991; Warrington et al., 1996). Vaast et al. (2006) found that coffee berries grown under full sun do not fill well and lack fat synthesis, which are reasons for low coffee quality. Shade decreases overall temperature by as much as 4ºC and in doing so slows berry growth, allows more time for the berries to fill, and ultimately gives coffee with higher sensorial quality (Vaast et al., 2006). This is particularly important for marginal, low-altitude areas (such as Mexico). In contrast, Bosselmann et al. (2009) showed that at high altitudes, with low temperatures and no nutrient or water deficits, shade trees may reduce sensory quality. Also, the occurrence of berry borer (*Hypothenemus hampei*) was lower at high altitudes and higher under shade.

Boot (2006) explains that coffee variety, which has a profound impact on the flavor profile of coffee, is key for quality differentiation and hence the market success of a single producer or even an entire district. For example, although not grown on the sites where we did our work, the Geisha variety has an outstanding quality record. In Colombia, the Caturra variety is consistently amongst the winners of the prestigious annual Cup of Excellence competition. For growers, however, the choice is to balance between quantity and quality. Varieties like Mundo Novo, Catuai, and Catimor are more popular for their higher yields, while varieties like Typica, Bourbon, and Caturra are renowned for their higher quality (Boot, 2006). Dwarf varieties (Caturra, Catimor, and Catuai) have a further advantage in that they can be planted at higher densities.

Fruit thinning is widely implemented to improve fruit growth and quality for many fruits such as peach, kiwi, and apple (Smith et al., 1992; Souty et al., 1999). Vaast et al. (2006) showed that fruit thinning decreases competition for carbohydrates between coffee berries and young branches, which can subsequently give higher quality. The difference between early to late harvests is essentially due to the competition of carbohydrates between berries and leaves. High crop load, and low leaf:fruit ratios result in a deficit of carbohydrate supply to fruits and thus competition between them leading to lower berry weight, lower bean size, lower biochemical composition and hence lower cup quality, especially for late-developing berries (Vaast et al., 2006).

6.2 Importance and relevance

Coffee-growing systems are complex and our work above shows that they are site-specific. Because of this, there is no option but to provide growers with the tools that will allow them to tailor management to their own particular site. Evaluating research results from on-farm experiments therefore requires a different framework than those from conventional reductionist experimentation, and includes the criteria of credibility, salience and legitimacy (Cash et al., 2003).

Conventional experimental science tends to work to produce results that can be repeated elsewhere under exactly the same conditions. It relies heavily on statistical criteria to test whether the results can be used to infer association or causality. In so doing, it focuses more on credibility or results than their salience or legitimacy. Participatory research uses a broader framework to define the problem in a way that is relevant (salient) to farmers, that is, it must include all relevant features of the problem. It must also be legitimate, that is, arrived at in a way that engages those who need to be involved, the producer. Conducting on-farm science, taking observations from 'normal' operations loses some of the clarity of results through loss of control, but increases the relevance and legitimacy by including those factors that the participants believe to be important.

The case studies we report here show that targeting biophysical characteristics in coffee farms for separate management and the appropriate choice of agricultural practices can have impact on the attributes of quality of the coffee beverage. These differences are not consistent across sites and not always statistically significant. Moreover, the impacts of the same biophysical variable or management practice can be negative at one site and positive at another.

Formal statistical tests of the significance of measured differences provide some guidance, but often mean little to commercial growers. The information provided by growers' own on-farm experimentation with biophysical variables and management practices has to be evaluated regarding their relevance, and whether it generates commercial, social and environmental benefits. The expected costs and benefits realized from decisions based on information from on-farm experimentation are the key criteria for growers. We discussed the management implications with growers 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 7).

Table 7 near here

Slope aspect as demonstrated previously often has a statistically significant and consistent impact on beverage quality (Avelino et al., 2005). In Concordia south-facing slopes scored the highest almost consistently while in Piendamo south-facing slopes scored the lowest, but east facing slopes and flat sites scored the highest for most quality attributes. We hypothesize that this is because the Piendam is more marginal for coffee than the Concordia site, which is in the heart of Colombia's coffee zone (*zona cafeteria*). The management implications of harvesting sites with differing slopes separately has only minor logistical implications and adds little to the cost of the production. The quality differences are remarkable considering that the sites with different aspect were only a few hundred meters apart, but the implications for a grower to achieve a better price for part of his crop are important.

Coffee from trees in upper slope positions score slightly higher than trees on lower position on the same slope. Although the differences are not significant in the data presented here, they are relevant, because growers' believe that upper slopes are less fertile and so give lower quality coffee. Our data do not support that belief, although soil fertility is often quoted as a basic factor affecting coffee quality It is generally accepted that fertile volcanic soils produce the best quality coffee, increasing both coffee acidity and body (Barel and Jacquet, 1994).

Varietal differences have significant impacts on quality characteristics as shown at the sites in the two Mexico sites. However, it is a major intervention to change varieties in a farm, and practically is an option only when farm renovation is being considered.

Shade management had substantial impacts on quality on both the Colombian and the Mexican sites. It is viable to manage shade, not only for the improvement of coffee quality, but because the shade trees also provide an additional source of income. It has long been maintained that shade was only a key factor for coffee plantations in sub-optimal growing zones (Beer et al., 1998). More recently it has been shown that shade is beneficial for coffee quality even in optimal coffee growing zones under a range of conditions (Bosselman et al., 2009; Vaast et al., 2005).

Fruit thinning had a favorable influence on coffee beverage quality in the Piendamo estate, but fruit thinning is not easy to implement and is labor intensive. Positive effects from fruit thinning were also shown in Costa Rica, where reduced fruit load significantly improved preference and acidity score (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. The effect is likely because Piendamo is somewhat marginal for coffee.

In the Piendamo estate, early harvest significantly improved beverage quality opposed to late harvest. This was also found in Costa Rica (Bertrand et al., 2005).

In the Concordia estate, the lower- and medium-canopy level scored higher than the higher-canopy levels, but the difference was not significant. In trials in Costa Rica, three-year-old trees gave the same results as here, but five-year-old trees were the opposite (Bertrand et al., 2005). Harvesting from different canopy levels requires a major logistic effort; thorough briefing of the pickers and probably strict supervisory control during the harvest and so is unlikely to be useful in practice.

6.3 Economic viability of systematic management

For the interpretation of the results, scores of 80 points are usually considered the entry level to specialty coffees and coffees with more than 85 points can generate substantial premiums for growers. At the time of this research, price premiums were US$1.35/ pound for grade A coffee with 80-83 points final score, US$1.55/pound for grade AA coffee with 84-87 points, and at least US$1.85/pound for grade AAA coffee with a final score 88-93 points. High quality boutique coffees (more than 93 points) often fetch more than US$3/pound of green coffee.

Applying this scheme, for example, to the cupping results of the different slope aspects in the estate farms, using aspect for separate management becomes commercially very interesting. The difference in the final score between the highest and lowest scoring aspect is 2.46 in the Concordia estate and 9.94 in the Piendamo estate. In Concordia the highest scores qualify as an AA premium. In Piendamo coffees from the south, east, northwest aspects can be sold as conventional coffees, while the eastern-aspect, and the plateau coffees would qualify for an A premium.

Reducing the fruit load obviously reduces the yield level of coffee trees. It has been estimated for 50% reduction of flower buds gives an actual yield decrease of 25% (Vaast et al., 2006). The best-performing sites reached an average green bean yield of 1.9 kg per tree when flowering buds were reduced by 50%. The grower could therefore expect about US$4.84 per tree at current prices on the NYBOT coffee exchange. 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 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. In the rare occasion that a boutique coffee would be produced due to the thinning of fruits, the grower could expect a return of US$12.10 per tree.

7. CONCLUSIONS

Possible interventions vary in terms of their ease of implementation, the likely improvement of quality that they cause and the resource intensiveness they require. However, together they provide distinct potential for added value of the product. Optimum management appears to be highly site specific so that it is not possible to make blanket recommendations. But by recognizing that quality is highly site specific, by means of continuous cycles of implementation, observation, interpretation and evaluation, each farmer could improve his management over time. By this means the farmer would be able to target the product to the dynamic requirements of a dynamic market. But to make this happen, it is necessary to interlink supply chain actors more closely, to facilitate data analysis and interpretation for farmers, and to develop appropriate feed-back mechanisms. Systematic targeting of agronomic farm management practices is a promising opportunity for farmers to improve their livelihoods by producing coffees with added value through chain-inclusive on farm experimentation.

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REFERENCES

Arcila-Pulgarín, J., Buhr, L., Bleiholder, H., Hack, H., Meier Wicke, U., 2002. Application of the extended BBCH scale for the description of the growth stages of coffee (*Coffea spp.).* Ann. Appl. Biol. 14, 19-27.

Avelino, J., Barboza, B., Araya, J.C., Fonseca, C., Davrieux, F., Guyot, B., Cilas, C., 2005. Effects of slope exposure, altitude and yield on coffee quality in two altitude terroirs of Costa Rica, Orosi and Santa Maria de Dota. J. Sci. Food Agric. 85, 1869-1876.

Barel, M., Jacquet, M., 1994. La qualité du café ses causes, son appreciation, son amélioration (Coffee quality: its causes, appreciation and improvement). Plantat. Recher. Developp. 1, 5-13.

Barrit, B.H., Rom, C.R., Konoshi, B.J., Dilley, M.A., 1991. Light level influences spur quality and canopy development and light interception influences fruit production in apple. Hort. Sci. 26, 993-999.

Beer, J., Muschler, R., Kass, D., Somarriba, E., 1998. Shade management in coffee and cacao plantations. Agrofor. Syst. 38, 139-164.

Bertrand, B., Etienne, H., Guyot, B., Vaast, P., 2005. Year of production and canopy region influence bean characteristics and beverage quality of Arabica Coffee, in: Liardon, R. (Ed.), Proceedings of the 20th International Conference on Coffee Science ASIC, ASIC, Lausanne, Switzerland, pp. 878-885.

Boot, W., 2006. Variety is the Spice of Coffee - Geisha and other varietals. Roast Magazine May June Issue.

Bosselmann, A.S., Dons, K., Oberthür, T., Smith Olsen, C., Ræbild, A., Usma, H., 2009. The influence of shade trees on coffee quality in small holder coffee agroforestry systems in Southern Colombia. Agric. Ecosyst. Environ. 129, 253-260.

Bramley, R.G.V., 2009. Lessons from nearly 20 years of Precision Agriculture research, development, and adoption as a guide to its appropriate application. Crop Pasture Sci. 60, 197–217.

Byers, A., Giovanucci, D., Liu, P., 2008. Value-adding standards in the North American food market. Food and Agriculture organization of the United Nations, Room. ISBN 978-92-5-105926-5.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Natl. Acad. Sci (USA) 100, 8086–8091.

Cassman, K.G., 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. Natl. Acad. Sci (USA) 96, 5952.

Cook, S.E., Bramley, R.V., 1998. Precision agriculture - opportunities, benefits and pitfalls of site-specific crop management. Aust. J. Exp. Agric. 38, 753.

Cook, S.E., O'Brien, R., Corner, R.J., Oberthür, T., 2004. Is precision agriculture irrelevant to developing countries? In: Stafford, J., Werner, A., (Eds.), Precision Agriculture, 4th European Conference on Precision Agriculture, Berlin, Germany, 15-19 June 2003, Wageningen Academic Publishers.

Coyle, W., Gehlhar, M., Hertel, T., Wang, Z., 1998. Understanding the determinants of structural change in world food markets. Am. J. Agric. Econ. 80, 1051-1061.

Daviron, B., Ponte, S., 2005. The coffee paradox. Global markets, commodity trade and the elusive promise of development. ZED BOOKS, London and New York, pp. 1-295.

Decazy, F., Avelino, J., Guyot, B., Perriot, J.J., Pineada, C., Cilas, C., 2003. Quality of different Honduran coffees in relation to several environments. J. Food Sci. 68, 2356-2361.

Dickson, P.R., Ginter, J.L., 1987. Market segmentation, Product differentiation and marketing strategy. J. Marketing 57, 1-10.

Dobermann, A., Blackmore, B.S., Cook, S., Adamchuk, V.I., 2004. Precision Farming: Challenges and Future Directions. New directions for a diverse planet, in: Fischer, T. (Ed), International Crop Science Congress. Brisbane, Australia. 2004 "New directions for a diverse planet". Proceedings of the 4th International Crop Science Congress, 6 Sep – 1 Oct 2004, Brisbane, Australia.

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1992. Multivariate data analysis with readings, Macmillan Publishing Company, New York.

Hijmans, R.J., Cameron, S., Parra, J., Jones, P.G., Jarvis, A., 2005. WorldClim - very high resolution global terrestrial climate surfaces for monthly temperature and precipitation. Int. J. Climatol. 25, 1965-1978.

Insightful, S-PLUS 6 Programmer's Guide, 2001. Insightful Seattle, Washington State, pp.1-1876.

Jaccard, J., Wan, C.K., 1996. Approaches to Interaction Effects in Multiple Regressions, Sage Publications, Thousand Oaks, California.

Läderach, P., Oberthür, T., Pohlan, J., 2009. Management of intrinsic Quality Characteristics for Specialty Coffee - A Framework Developed and Tested in Coffee growing regions across Latin America. Verlag Dr Müller. Saarbrücken, Germany, pp. 1-157. ISBN: 978-3-639-22143-5

Lingle, T.R., 2001. The Coffee Cuppers Handbook – A Systematic Guide to the Sensory Evaluation of Coffee's Flavor. Specialty Coffee Association of America ASIC, 3rd edition, Long Beach, California, pp. 1-71.

Marín, L.S., Arcilla, P.J., Montoya, R.E., Oliveros, T.C., 2003. Cambios físicos y químicos durante la maduración del fruto de café (*Coffea arabica L. var. Colombia*) (Physical and chemical changes during the maturation of coffee (*Coffea arabica L. var. Colombia*) berries). Cenicafe 54, 208-225.

Morlat, R., Bodin, F., 2006. Characterization of viticultural terroirs using a simple field model based on oil depth - II. Validation of the grape yield and berry quality in the Anjou vineyard (France). Plant Soil 281, 55-69.

Muschler, R.G., 2001. Shade improves coffee quality in a sub-optimal coffee-zone of Costa Rica. Agrofor. Syst. 52, 1-253.

Niederhauser, N., Oberthür, T., Kattnig, S., Cock, J., 2008. Information and its management for differentiation of agricultural products: the example of specialty coffee. Comput. Electron. Agr. 61, 241-253.

Oberthür, T., Barrios, E., Cook, S., Usma, H., Escobar, G., 2004. Increasing the relevance of scientific information in hillside environments through understanding of local soil management in a small watershed of the Colombian Andes. Soil Use Manage. 20, 1-23.

Regentinstruments, WinSCANOPY for Hemispherical Image Analyses, 2005. Manual and CD, Regent Instruments Inc, Canadá, pp. 1-105.

Salette, J., Asselin, C., Morlat, R., 1998. The relationship between "terroir" and product: an analysis of the "terroir-vine-wine" system and its analogous application to other products. Sci. Aliments. 18, 251-265.

Smith, G.S., Gravett, I.M., Edwards, C.M., Cúrtis, J.P., Buwalda, J.G., 1992. Spatial analysis of the canopy of kiwifruit vines as it relates to the physical chemical and post harvest attributes of the fruit. Ann. Bot. 73, 99-111.

Souty, M., Génard, M., Reich, M., Albagnac, G., 1999. Influence de la fourniture en assimilats sur la maturation et la qualité de la pêche (*Prunus persica L. 'suncrest'*). Can. J. Plant. Sci. 79, 259-268.

Staub, C.1995. Roast Color Classification System Developed by Agtron-SCAAA. Specialty Coffee Association of America ASIC, Long Beach, California.

Vaast, P., Bertrand, B., Perriot, J.J., Guyot, B., Genard, M., 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica L.*) under optimal conditions. J. Sci. Food Agric. 86, 1-197.

Vaast, P., van Kanten, R., Siles, P., Dzib, B., Franck, N., Harmand, J.M., 2005. Shade: A Key Factor for Coffee Sustainability and Quality. In: Liardron, R. (Ed.), Proceedings of 20th International Conference on Coffee Science ASIC, ASIC, Lausanne, Switzerland, pp.1-8.

Warrington, I.J., Stanley, C.J., Tustin, D.S., Hirst, P.M., Cashmore, W.M., 1996. Light transmission, yield distribution, and fruit quality in six tree canopy forms of ‘Granny Smith’ apple. J. Tree Fruit Prod. 1, 27-54.

Table

Table 1. Summary of different biophysical variables and management practices examined at the various case-study sites. Note that not all variables and practices were represented at all sites.

	Biophysical variables and management practices						
	Aspects[1] (#)	Slope position [2]	Varieties (#)	Shade	Fruit thinning	Canopy level[3]	Harvests (#)
Concordia[i]	5	2	1	None	50%	3 levels	1
Piendamo[ii]	5	2	1	None	50%	Whole tree	2
Inza small farms[iii]	VNA5[6]	VNA[5]	1	VA[4]	None	Whole tree	VNA[5]
El Encinal [iv]	Flat	1	4	VA[4]	None	Whole tree	1
Axcocuapan[v]	Flat	1	2	VA[4]	None	Whole tree	1

[i] 9 (30x30m) sampling units (4 aspects with each two slope positions and flat), 2 management practices (fruit thinning and canopy level) with 4 treatments (fruit thinning, control, low, medium and high canopy level) with a total of 45 treatments and minimum of 2 samples per treatment.
[ii] 9 (30x30m) sampling units (4 aspects with each two slope positions and flat), 2 management practices (fruit thinning and harvest time) with 4 treatments (fruit thinning, control early and late harvest) with a total of 36 treatments and minimum of 2 samples per treatment.
[iii] 31 (30 x 30m) sampling units in small farms with different shade levels (37-87%), minimum of two samples per plot
[iv] 4 varieties (Typica, Mundo Novo, Caturra Rojo, Caturra amarillo) differnt shade levels (43-95%), with a total of 8 treatments and (4 varieties, low and high shade levels) 2-4 samples per treatment.
[v] 2 varieties (Typica, Caturra Rojo) with different shade levels (48-92%), with a total of 4 treatments (4 varieties, low and high shade levels) and 2-4 samples per treatment.
[1]Aspect (north, east, south, west and flat; in Concordia northwest instead of north).
[2] Lower and upper slope position.
[3] Number of horizontal strata harvested.
[4] VA = variable analyzed here.
[5] VNA = variable not analyzed here.

Table 2. Descriptive statistics for all sites including the two Colombian estates (Concordia, Piendamo), the small farms of Inza in Colombia and the two Mexican farms (El Encinal, Axocuapan). Samples for all biophysical variables and management practices are included in the analyses.

		Aroma fragrance	Acidity	After-taste	Body	Flavor	Sweetness	Preference	Final score
Piendamo n=139	Minimum	4.00	5.00	3.75	7.00	4.00	6.00	4.00	59.8
	Mean	7.53	7.60	7.04	7.90	7.33	7.83	7.08	78.1
	Median	7.75	7.75	7.00	8.00	7.50	8.00	7.25	80.0
	Maximum	9.00	9.25	9.50	9.00	9.25	10.00	9.75	91.5
	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	63.5
	Mean	7.64	7.82	7.43	7.99	7.85	8.13	7.83	82.3
	Median	7.75	8.00	7.25	8.00	8.00	8.00	8.00	81.9
	Maximum	9.00	9.25	10.00	9.00	10.00	10.00	10.00	92.0
	Std devn.	0.72	0.64	0.98	0.58	0.86	0.92	0.94	5.03
Inza n=33	Minimum	2.00	3.00	4.00	3.00	4.00	2.00	3.00	39.0
	Mean	6.05	5.78	5.77	5.56	5.77	2.83	5.37	54.6
	Median	6.00	6.00	5.00	5.50	5.00	3.00	5.50	54.0
	Maximum	8.00	8.00	8.00	9.00	8.00	5.00	8.00	77.0
	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	na [1]	4.80	na	na	na	na
	Mean	9.73	8.27	na	6.00	na	na	na	na
	Median	9.70	8.30	na	6.05	na	na	na	na
	Maximum	11.40	10.40	na	7.20	na	na	na	na
	Std devn.	0.58	0.89	na	0.42	na	na	na	na
Axocuapan n=48	Minimum	8.20	6.70	na	4.70	na	na	na	na
	Mean	9.52	8.81	na	6.07	na	na	na	na
	Median	9.50	8.80	na	6.10	na	na	na	na
	Maximum	11.10	11.40	na	7.00	na	na	na	na
	Std devn.	0.58	1.09	na	0.50	na	na	na	na

[1] na = not available

Table 3. One-way ANOVA and t-test on coffee beverage quality for aspect and position in the slope for samples from the Concordia and Piendamo estates. 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	Aroma fragrance	Acidity	After-taste	Body	Flavor	Sweetness	Preference	Final score
Aspect Concordia estate Duncan's multiple range test								
North	7.75 a	7.73 ab	7.17 b	7.90 a	7.78 ab	8.22 a	7.68 a	81.86 a
East	7.58 ab	7.62 ab	7.24 b	7.57 a	7.52 b	7.78 a	7.61 a	80.75 a
South	7.15 b	7.89 ab	7.90 a	7.86 a	8.11 a	8.25 a	8.05 a	82.94 a
West	7.56 ab	7.35 b	7.16 b	8.07 a	7.89 ab	8.21 a	7.81 a	81.63 a
Flat	7.75 a	8.12 a	7.65 ab	7.87 a	7.85 ab	8.06 a	7.66 a	83.21 a
Aspect Piendamo estate Duncan's multiple range test								
Northwest	6.92 b	7.06 ab	6.28 bc	7.96 a	6.81 ab	7.53 ab	5.91 b	73.63 ab
East	7.91 a	7.85 a	7.45 a	7.87 a	7.75 a	8.08 a	7.37 a	80.94 a
South	7.21 b	6.92 b	5.71 c	7.37 a	6.25 b	7.05 b	6.01 b	71.00 b
West	7.28 b	7.20 ab	6.70 abc	7.91 a	7.81 ab	7.47 ab	6.61 ab	74.94 ab
Flat	7.47 ab	7.47 ab	6.94 ab	8.03 a	7.47 a	7.84 ab	6.81 ab	78.16 ab
Slope position Concordia estate Duncan's multiple range test								
High	7.46 a	7.65 a	7.41 a	7.81 a	7.79 a	8.14 a	7.71 a	81.74 a
Low	7.56 a	7.62 a	7.28 a	7.83 a	7.78 a	8.01 a	7.83 a	81.56 a
Slope position Piendamo estate Duncan's multiple range test								
High	7.46 a	7.43 a	6.53 a	7.99 a	6.96 a	7.71 a	6.48 a	76.36 a
Low	7.17 a	7.04 a	6.51 a	7.52 a	6.81 a	7.31 a	6.43 a	73.56 a

Table 4. One-way ANOVA and t-test on beverage quality at the El Encinal and Axocuapan farms in Mexico. 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	Body
Varieties El Encinal ANOVA			
Typica	9.45 a	8.03 a	6.1 a
Red Caturra	10.17 b	9.02 b	5.9 a
Mundo Novo	9.78 ab	8.22 a	5.9 a
Yellow Caturra	9.57 a	7.80 a	6.0 a
Varieties Axocuapan t-test			
Typica	9.81 b	8.70 a	6.2 b
Red Caturra	9.22 a	8.95 a	5.8 a

Table 5. T-test analyses on beverage quality for shade level samples from in Inza, 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	Sweetness	Preference	Final score
Inza								
21-50	5.89 a	5.55 a	5.50 a	5.13 b	5.41 a	2.97 a	5.18 a	53.2 a
51-73	6.18 a	6.06 a	6.07 a	6.06 a	6.21 a	2.67 a	5.21 a	56.3 a
El Encinal								
43-75	9.79 a	8.36 a	na	6.1 a	na	na	na	na
76- 95	9.68 a	8.19 a	na	5.9 b	na	na	na	na
Axocuapan								
48 - 75	9.68 a	8.96 a	na	6.2 a	na	na	na	na
77 - 92	9.39 a	8.96 a	na	5.9 b	na	na	na	na

na = not available

Table 6. Duncan multiple range test on coffee beverage quality for 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). Data for the same attribute followed by the same letter are not significantly different (P<0.05 Duncan multiple range test).

Treatment	Aroma fragrance	Acidity	After-taste	Body	Flavor	Sweetness	Preference	Final score
Fruit thinning (%) at Concordia estate, Duncan's multiple range test								
0	7.77 a	7.88 a	7.85 a	8.07 a	8.08 a	8.47 a	8.00 a	84.26 a
50	7.68 a	7.63 a	7.21 b	7.35 a	7.66 a	7.97 a	7.71 a	81.10 b
Fruit thinning (%) at Piendamo estate, Duncan's multiple range test								
0	7.50 a	7.09 a	6.43 a	7.70 a	6.79 a	7.51 a	6.38 a	74.62 a
50	7.16 a	7.46 a	6.71 a	7.90 a	7.12 a	7.61 a	6.62 a	76.18 a
Harvest time at Piendamo estate, Duncan's multiple range test								
May 12	7.26 a	7.55 a	6.87 a	7.85 a	7.35 a	7.66 a	6.95 a	77.77 a
June 09	7.41 a	6.94 b	6.19 b	7.73 a	6.49 b	7.43 a	5.97 b	72.56 b
Canopy level harvest at Concordia estate, Duncan's multiple range test								
Low	6.93 b	7.73 a	7.56 a	7.76 a	7.70 ab	8.20 ab	7.73 a	81.56 a
Medium	7.51 a	7.91 a	7.37 a	8.03 a	8.11 a	8.01 ab	7.70 a	82.25 a
High	7.67 a	7.35 a	7.06 a	8.05 a	7.48 b	7.81 b	7.68 a	80.51 a

Table 7. Evaluation of management interventions by their statistical significance, ease of implementation, likely improvement of quality, resource intensiveness, and added value.

Management	Statistical significances	Ease of implementation	Improvement of quality	Resource intensiveness	Added value[1]
Aspect	Medium	Easy	High	Low	High
Variety	Medium	Medium	Low - medium	High	Low – medium
Soils	Low	Medium	Low	Medium	Low
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 levels	Medium	Easy	Medium	Low	Low

[1] Benefit – cost.

Figure

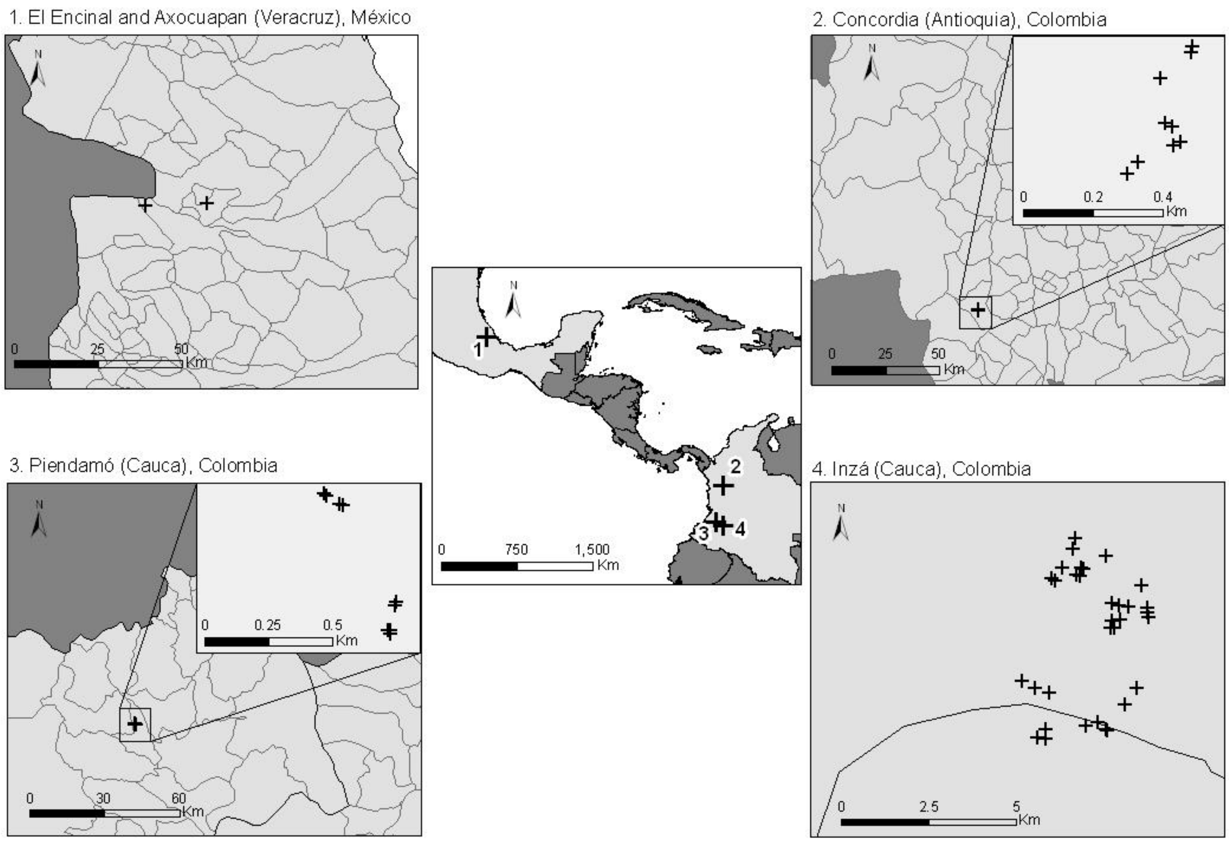

Figure 1. The study included the Colombian estates Concordia (Antioquia) and Piendamo (Cauca), 33 small farms in Inza (Cauca, Colombia) and two farms in Veracruz (Mexico), one in El Encinal and one in Axocuapan.